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Engineering Evaluation of UXO Detection Technologies and Interrogation Methodologies For Use in Panama: Empire, Balboa West and Piña Ranges

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13. ABSTRACT (Maximum 200 words)

This report covers the UXO detection technology and interrogation methodology evaluations conducted on site in Panama on the Empire, Balboa West and Piña Ranges. The data collected was used to evaluate the capabilities and limitations of UXO detection technologies and interrogation methodologies in Panama. This report provides a summary of commercially available technologies and examines the issues associated with implementing technologies in the Panamanian environment. Impacts to the environment are examined to determine the effects technologies would potentially have on the environment if implemented.

14. SUBJECT TERMS

Unexploded Ordnance (UXO), Panama, Empire Range, Balboa West Range, Piña Range, Engineering Evaluation, UXO detection, UXO Interrogation, Detection Technologies, Probability of Detection, False Alarm Rates

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Executive Summary

As part of the process of transferring the Empire, Piña, and Balboa West Ranges to the Government of Panama (GoP) the Panama Canal Treaty Implementation Plan Agency (TIPA) has tasked the U.S. Army Environmental Center (USAEC) and the Naval Explosive Ordnance Disposal Technology Division (NAVEODTECHDIV) with conducting an Engineering Evaluation (EE) effort on various unexploded ordnance (UXO) detection technologies and interrogation methodologies in Panama. The effort involved evaluating several of the most promising commercially available UXO detection technologies to look at their effectiveness and to determine the capabilities and limitations of UXO detection technologies in the Panamanian environment. The purpose of this report is to convey the results of the UXO detection technology and interrogation methodology evaluations conducted in the unique Panamanian environment. Technology implementation issues are covered which discuss the variables effecting the implementation of UXO detection technologies and interrogation methodologies including a site accessibility analysis. Environmental impacts are also examined including the potential impacts to the soil, vegetation, and wildlife, which may occur if UXO detection and interrogation technologies are implemented.

An overview of the environment, UXO survey and interrogation processes, and UXO detection technologies and platforms are presented in the report as background. Maximum probable ordnance penetration depths are also presented and discussed. Maximum ordnance penetration depths are important because they are compared to the capabilities of the UXO detection technologies evaluated as part of this report and it was shown that even the best sensor was not capable of detecting all ordnance items to their respected maximum penetration depth.

A total of six sensors were examined from two sensor categories: passive magnetometers and active electromagnetic (EM) sensors. Three specific technologies from the first category, passive magnetometry, were selected: a cesium vapor magnetometer system using a Geometrics™ G858 magnetometer, the Schonstedt™ magnetic locator, and the Ferex 4.021 (Mk 26) ferrous locator. Three active EM systems were selected including the Geonics™ EM 61 time domain metal detector, the Vallon MW 1630 (Mk 29) all metals locator, and the White 6000/Di Pro SL all metals locator. A third category, the multi-sensor approach, is merely a combination of two or more sensors from the various categories and was also examined.

Actual sensor performance is difficult to predict without a thorough understanding of the intended targets and the environment the sensor is being asked to operate in. It is therefore necessary to establish a rough

baseline of performance for each sensor considered in an ordnance sweep to determine the following parameters: (1) the maximum target to sensor detection range (depth or Z spatial component); (2) the minimum spacing to be used in a geophysical survey to ensure that the signal produced by the presence of the ordnance fall within the detectors field of view (longitude / latitude or X / Y spatial components); (3) the probability of detection (P_D); (4) the proper detector to use given specific ordnance targets; and (5) geophysical constraints such as ambient magnetic noise, terrain, and vegetation which effect the implementation of the technologies. To establish a baseline for the first two parameters two separate evaluations were conducted in Panama. The two evaluations included the maximum detection range evaluation and the sensor field of view evaluation. The third, fourth, and fifth parameters are also explored in this report.

To estimate the maximum detection range of each sensor, an area on the Empire Range was selected, marked off, and cleared of magnetic and conductive materials. Test targets were then placed within the "clean" test area and each sensor was positioned directly over the target and was moved, in a vertical direction upward until the sensor could no longer detect the presence of the item. At that point, the distance from the center of the target to the bottom of the sensor head was measured. The distance represented the maximum detection distance for that particular sensor and target combination. A conservative approach was taken including setting the detector at maximum sensitivity and using air as the medium because soil would attenuate the signal from buried ordnance, thus decreasing the detection range. This conservative approach was used to ensure that distances obtained represented the absolute maximum or "best-case" detection ranges. The results are shown below in Table ES-1.

Table ES-1 Maximum Detection Range In Air

Target (Appendix A)	Schonstedt	Mk 26	Mk 29	White	EM61 HH	G858	Reliable Detection Depth	Max Penetration
37mm projectile	65	70	45	34.5	41	60	30.5	152.4
60mm mortar	48	53.5	50	38	31	55	61	91.4
81mm mortar	59	87	56	50	51*	74*	NA	NA
105mm projectile	75	184	64	58	60*	100*	121.9	350.5

*Data was Extrapolated All Values in Centimeters

The greatest detection range for each particular target has been highlighted. The table shows that the Mk 26 gradiometer has the greatest detection range, particularly for larger ordnance items such as the 105mm. The gradiometer detectors (Schonstedt, G858, and Mk 26) were consistently better than the active EM detectors (Mk 29, EM61 HH, and White).

When the measured maximum detection ranges are compared to the maximum probable penetration depths for each of the test targets it is obvious that even under the best conditions the detectors are not technically capable of detecting items down to the maximum penetration depth.

From the results of the evaluation, technologies are not currently available to detect 100% of the potential UXO items on the ranges in Panama. The only effective method of clearing an area down to the estimated maximum penetration depth would be to survey and remove layer by layer until the maximum penetration depth is reached.

Despite the limited range of the detectors to find deeply buried items, the sensors are effective in finding shallow buried targets but only when properly employed. Whenever practical, ordnance detection surveys are usually conducted in grids so that data analysis tools can be brought to bear on the problem. The gridded area is usually surveyed in a series of parallel survey lanes, which are run consecutively, until the entire area has been covered. Generally, the data is not rectilinear in nature and tends to be "sample rich" in the direction of travel and "sample poor" perpendicular to the direction of travel. The terms "sensor swath width" or "sensor spacing" are used to define the distance between parallel lanes of travel and often contain 10% or even 20% of the samples that exist along the line of travel. If, for example, a sensor samples at 10 hertz and the distance covered in one second is one meter and constant velocity is assumed, a reading is collected every 10 cm at regularly spaced intervals. If the swath width is one meter, the perpendicular sample space is 100 cm or 10 times as far. For accurate surveys, and in order to minimize the number of targets potentially missed during the survey, the minimum swath width or sample spacing must be calculated. This evaluation is also referred to as the spatial detection in the horizontal plane. An evaluation was conducted to determine the sensor field of view or how far in the horizontal plane can the sensor be and still detect the item.

For the field of view evaluation, a test grid was constructed on Empire Range measuring 2 meters by 2 meters, with the center of the grid at location (0,0) in Cartesian coordinates. The area was swept clean of any sources of magnetic or conductive material (noise) that could influence the evaluation. The area was then gridded with string denoting .25, .50, 1, and 2 meter spacing in the X, Y field. Test targets were placed in the center of the grid (0,0) on the ground with longitudinal axes facing north. The detector was then placed at each node and readings were taken at heights above the target at .25, .50 .75 and 1 meter increments. Taking readings at the various positions allowed for a 3-dimensional view of the item with respect to the sensor (how the sensor was affected by the target with respect to their relative orientations). Two detectors were evaluated (the Mk 29 and the Mk 26) because they were the best representatives of their respective technologies (passive magnetometer and EM induction) according to the maximum detection range detection tests.

The values taken at each 3-dimensional node were then plotted in a magnitude map for each sensor and each target configuration and are included in the report as an appendix. Each magnitude map shows the gradient magnetic field distribution at the specified constant height. The signal strength at each given node (x, y, and z) is represented by colors on the magnitude map. Subtracting out the "dc bias" component of the data, also known as normalization, the dynamic range of these values can be calculated. Using the dynamic range and the ambient noise readings one can determine the minimum threshold signal strength that would be indicative of a valid target and not attributable as part of the ambient magnetic field. The minimum threshold signal strength is usually defined as a factor of four times the ambient noise level after normalization.

From the magnitude maps, it was determined that the optimal spacing width is .5 meters for both the Mk26 and Mk 29 detectors. Although spatial distribution testing is an important metric for sensors and their operators, operating detectors in an environment like Panama may not be conducive to survey areas where well-defined lanes can not be established and maintained. For example, during the Site Investigation (SI) transect surveys the detectors had to be used in a "mag and flag" mode because of the difficulties experienced with the terrain and navigation. The "mag and flag" mode involves marking anomalies for interrogation in the field during the survey process. The rough terrain made it very difficult to maintain straight well-defined swaths at an even pace which is required when the systems odometers are used to link the sensor data with a positional data (GPS was not an option because of the jungle canopy). A further analysis of terrain and the difficulties associated with implementing UXO detection technologies is explored in the report.

Using targets similar to the ones expected to be on the ranges in Panama UXO detection technologies were also evaluated to determine their respective probabilities of detection (P_D) in the Panamanian environment. A variety of target scenarios were created using 33 inert ordnance items buried at a calibration reference area that was established on the Empire Range. The G858, EM61 cart, and EM61 Hand Held (HH) were each used at the calibration reference area in an attempt to evaluate the ability of each sensor to locate buried targets. The P_D for each sensor is calculated by dividing the number of anomalies correctly selected by the total number of anomalies buried in the reference area.

Each sensor reported a substantial number of more selections than available targets or false alarms. False alarms are the target selections that were not made from ordnance items. The G858, EM61 cart and EM61 HH sensors reported a false alarm ratio (FAR) which is the number of false alarms (reported targets minus correct selections) divided by the number of ordnance items detected (correct selections) of 1.94, 1.27, and 2.35 respectively. The P_D and FAR values for each sensor are presented in Table ES-2.

Table ES-2 Probability Of Detection And False Alarm Ratio (FAR)

Sensor	Reported Targets	Correct Selections	Available Targets	P_D	FAR
G858 Mags	47	16	33	48.5%	1.94
EM61 Cart	50	22	33	69.7%	1.27
EM61 HH	77	23	33	66.7%	2.35

Besides system performance issues (maximum detection range, sensor field of view, and P_D), there are several other implementation issues which must be considered if the technologies are to be used in the Panamanian environment. These issues concerning implementation include method of employment (platform), false alarms, and site accessibility. For each issue, the purpose or relevance is presented along with a summary of the findings and results concerning the issue.

From the initial technology evaluation report, and from the recent UXO SI effort conducted in Panama, it was determined that man-portable UXO detection technologies would be most appropriate for use in Panama. Vehicular platforms could only be used in very limited areas of the ranges while airborne systems would not be effective at all in the Panamanian environment due to the jungle canopy. Therefore, the areas surveyed in the recent SI effort were done with the man-portable systems. The EM61 in the cart and hand held configurations was used on the transects, however it was quickly discovered that the terrain was a factor in configuration selection. At moderately steep terrain (16-25% grade) the man-portable cart configurations were very rigorous to use and were abandoned for the HH configurations.

As noted earlier, sensors often report more targets than are actually UXO; these "extra" targets are called false alarms. The FAR values become important when implementing UXO detection and interrogation technologies in an area because they represent the magnitude of effort associated with UXO recovery. The FARs calculated from the calibration reference area analysis, were 1.94, 1.27, and 2.35 for the G858, EM61 cart and EM61 HH respectively. For example, if the G858 system were used to survey an area almost twice as many targets would have to be interrogated for every ordnance item recovered. The EM61 cart would have 1.27 times as many false alarms while the EM61 HH would have 2.35 times as many. Calculating the similar statistics for all sensors combined, in a multi-sensor approach, yields a P_D of 94% but a false alarm rate of 4.61 (almost 5 false alarms would be dug for every ordnance item recovered). High FARs are indicative of the major problem with UXO detection technologies in general, their ineffectiveness in discriminating between UXO and non-UXO targets.

Even if the technologies could find all or even most of the targets, in order to implement UXO detection technologies in a UXO concentration area, by definition the site must be accessible and traversable. There are several factors, which effect site accessibility and the ability to traverse an area including vegetation and terrain. The greater the vegetation and the steeper the terrain the more difficult it becomes to access and traverse the area. In addition, standard Explosive Ordnance Disposal (EOD) or UXO removal procedures, require overgrowth and vegetation to be cleared before personnel can safely enter due to concerns with unplanned encounters with UXO items. The level of effort required to implement technologies in an environment, therefore, is dependant upon the amount of overgrowth removal required and the local terrain.

Overgrowth removal is a difficult and time-consuming task. It is very conceivable that the site preparation phase of the UXO process could take much longer than the actual survey phase because of the amount of overgrowth and vegetation that must be removed. As the density of overgrowth and vegetation increases the level of effort required to clear the site so the ground is visible and traversable increases. The ranges in Panama are located in a jungle environment, which possess even greater vegetation and overgrowth removal challenges.

Assuming that the site is cleared and surface swept, the area is ready for a subsurface survey with UXO detection technologies. Current man-portable detection technologies require the operator to carry the sensor and associated equipment over the area of concern. Navigating through a range or impact area with the UXO detection equipment is demanding and exhaustive work even in areas where the terrain is flat and level. As the slope increases, the ability to negotiate the area and stay on course with the survey pattern decreases to the point where the operator has to focus more on stability and balance than the survey itself. The sensors usually need to be positioned at a constant height above the ground with relatively low amounts of lateral motion. The detectors are highly sensitive where excessive swinging or sensor movement can skew the data. Keeping the sensor in the constant proper orientation is very challenging and gets tougher as the terrain gets worse. The challenge increases exponentially with an increasing grade. In addition the heat and humidity in the tropic environment make the challenging task even tougher. The report examines the qualitative level of effort associated with implementing technologies on various terrain and vegetation scenarios common to Panama.

After an area has been surveyed with a detector or series of detectors and a target list is generated the next step in the UXO process is to interrogate those targets to determine if they are UXO. Specifically UXO interrogation refers to various UXO clearance activities, including excavating and positively identifying UXO. The report evaluates the capabilities and limitations of various UXO interrogation methodologies including manual methods and robotic methods. Manual UXO interrogation methods use human energy and are performed entirely without mechanized equipment. Remote-controlled UXO interrogation systems include tele-robotic and autonomous systems. In general, remote-controlled UXO interrogation systems are mechanized systems that can be controlled remotely thus taking the operator outside the area of immediate hazard area. Manual UXO interrogation methods are inherently dangerous for the operator especially in areas with steep terrain. Manual interrogation is effective, however, as the depth increases the level of effort increases dramatically. The tele-robotic systems evaluated in this report performed very well in the Panamanian environment but experienced great difficulty in steep terrain.

Any UXO clearance operation will have an impact on the environment. These environmental impacts are a function of the technologies implemented the level of disturbance (depth of target interrogation), and the local environment conditions of the area. A qualitative analysis is presented which examines the short-term and long-term environmental impacts associated with the implementation of UXO detection and interrogation technologies. Environmental impacts examined include impacts on the soil, vegetation, and wildlife.

Using man-portable detection technologies alone would cause small disturbances on the surface of the soil, however the removal of vegetation from the ranges that is required prior to implementing UXO detection and interrogation technologies would impact the environment. Surface soil erosion resulting from vegetation loss is also a potentially significant concern for the ranges in Panama and can result in increased siltation into the canal. Interrogating deep targets would require large amounts of soil to be disturbed and removed which would cause long-term impacts to the environment and the canal.

Wildlife would also be effected by the implementation of UXO detection and interrogation technologies. The ranges contain many species of plants, mammals, and birds, which are globally imperiled, nationally imperiled, or protected under Panamanian Law. Short-term impacts on wildlife would primarily take the form of species displacement during vegetation burning and ground-based activities. Long-term impacts on wildlife resources would include loss of habitats and potential loss of threatened and endangered species.

In addition to impacting the environmental, implementing UXO detection technologies or interrogation methodologies in Panama will subject EOD or UXO removal personnel to a hazardous environment. The hazard level for performing UXO detection and interrogation tasks is a function of the types and quantities of ordnance present, the technology or methodology implemented, and the local environmental conditions of the site.

In conclusion, there are no commercial technologies available today that are capable of detecting 100% of the potentially buried UXO on the ranges in Panama. However, UXO detection technologies are capable of detecting some of the UXO in the Panamanian environment but have limited capabilities and require a large amount of effort to implement. Given the extreme environmental conditions in Panama, man-portable UXO detection technologies used in the "mag and flag" mode of operation are the most appropriate for locating buried UXO. However, the terrain and vegetation are limiting factors in accessing UXO concentration sites. Before any additional UXO detection and interrogation efforts are undertaken on the ranges in Panama, impacts to the environment should be weighed against the potential benefit from implementing such technologies and the hazard to the EOD or UXO specialists that will potentially perform the work. In addition any actions performed on the ranges must be implemented in a manner consistent with the "protection" of the environment according to the Treaty.

1.0 INTRODUCTION

1.1 Purpose

As part of the process of transferring the Empire, Piña, and Balboa West Ranges to the Government of Panama (GoP) the Panama Canal Treaty Implementation Plan Agency (TIPA) has tasked the U.S. Army Environmental Center (USAEC) and the Naval Explosive Ordnance Disposal Technology Division (NAVEODTECHDIV) with conducting an Engineering Evaluation (EE) effort on various unexploded ordnance (UXO) detection technologies and interrogation methodologies in Panama. The EE effort supports the U.S. Army South (USARSO) and the U.S. Air Force (USAF) range transfer process. The effort involved evaluating several of the most promising commercially available UXO detection technologies to look at their effectiveness and to determine the capabilities and limitations of UXO detection technologies in the Panamanian environment. UXO interrogation methodologies including manual and remote-controlled systems were also evaluated in this effort. The purpose of this report is to convey the results of the UXO detection technology and interrogation methodology evaluations conducted in the unique Panamanian environment. Technology implementation issues are covered which discuss the variables effecting the implementation of UXO detection technologies and interrogation methodologies including a site accessibility analysis. A trade off analysis is also presented which examines the effects that the technologies and methodologies would likely have on the environment if implemented.

1.2 Background

In order to characterize the ranges and to identify the hazards that may currently exist on the Empire, Balboa West, and Piña Ranges, TIPA tasked USAEC and NAVEODTECHDIV to conduct an UXO assessment of the three ranges. The UXO Assessment report was a preliminary assessment of the areas based on historical research and an archive record search. The report was finalized in January 1997 and is entitled "Unexploded Ordnance Assessment of U.S. Military Ranges in Panama: Empire, Balboa West, and Piña Ranges".

In addition to the UXO Assessment report, an initial evaluation of UXO detection and interrogation technologies that are potentially applicable in Panama was conducted. The purpose of this report was to provide background on the different UXO detection and interrogation technologies available and to provide a qualitative cost-benefit or "trade off" analysis of the effects that implementation of these technologies might have on the environment. The report entitled "Evaluation of UXO Detection and Interrogation Technologies For Use in Panama: Empire, Balboa West, and Piña Ranges" was finalized in January 1997. The report was based upon data and experiences from the Advanced Technology Demonstrations (ATDs) conducted at Jefferson Proving Grounds (JPG) as part of the UXO clearance technology program managed by USAEC and NAVEODTECHDIV.

Because both initial reports were based on written records or studies which were not verified with field data, TIPA, USARSO and the U.S Air Force Air Installation Logistics Environmental Restoration (ILEVR) Office undertook a Site Investigation (SI) effort. The SI effort focused on conducting UXO sampling, UXO characterization and limited UXO clearance activities on specific portions of the Empire, Balboa West and Piña Ranges. The field data collected from the SI effort was combined in a report entitled "Unexploded Ordnance Site Investigation of U.S. Military Ranges in Panama: Empire, Balboa West and Piña Ranges", dated July 1998. The purpose of the SI effort was to refine and/or confirm the UXO assessment on certain areas delineated in the initial assessment report and to provide ground truth data on UXO concentration levels and hazard levels for the three ranges in Panama. As a follow-up to the SI report, this EE effort was undertaken. The EE effort, which is covered in this report, concentrates on the evaluation of UXO detection technologies and UXO interrogation methodologies for use in Panama. Several UXO detection technologies and interrogation methodologies were evaluated in Panama during the SI and EE efforts. The capabilities, limitations, and implementation issues associated with UXO detection technologies and interrogation methodologies are also covered in this report. This report provides ground truth data on the system performance in the Panamanian environment.

1.3 Project Goals and Report Outline

The overall goal of this report is to technically evaluate UXO detection technologies and interrogation methodologies that are potentially applicable for use in the Panamanian environment. The report will serve as a guide in determining the capabilities and limitations of several available promising UXO detectors and UXO interrogation methodologies for use in Panama. The report also evaluates the issues associated with implementing technologies and methodologies in the Panamanian environment including site accessibility and the level of effort required in implementing the UXO detection technologies and interrogation methodologies. A trade off analysis is provided which examines the environmental impacts associated with implementing such technologies and methodologies.

The report is organized into 11 major sections not including the introduction. The sections include the following: environmental conditions; surface and subsurface UXO concentrations; UXO detection process; UXO detection technologies; UXO detector evaluations; detailed analysis of SI data; UXO detection technology findings, results and implementation issues; UXO interrogation process; UXO interrogation evaluation findings / results; environmental impacts and UXO hazards, and conclusions for the EE. A description of each section is presented below.

The environmental conditions of an area greatly effect the performance and implementability of UXO detection technologies and interrogation methodologies. Panama has a unique environment, which effects the performance of technologies. An environmental characterization was conducted for the initial report entitled "Evaluation of UXO Detection and Interrogation Technologies For Use in Panama: Empire, Balboa West and Piña Ranges", and was updated and is presented as background.

The surface and subsurface UXO Concentration section presents UXO concentrations in terms of a three dimensional problem. Ordnance penetration depths are presented and discussed. Ordnance penetration depths are important because they are compared to the capabilities of the UXO detection technologies evaluated as part of this report.

The UXO Detection Process section summarizes the process associated with detecting UXO both surface and subsurface. Included in this section is a brief description of the site preparation and logistics issues associated with UXO surveys.

The UXO Detection Technology section provides a short description of each of the detectors used throughout the various evaluations. A system description and method of employment is included for each system used in the EE effort.

The UXO Detection Technology evaluation section covers two specific UXO detection evaluations that were conducted to examine the capabilities and limitations of various detection technologies in the Panamanian environment including the maximum detection range evaluation and the detector field of view evaluation. UXO detection technology platforms are also discussed with respect to the local environment including the implementability of the various configurations.

The Detailed Analysis of SI Data section presents a detailed analysis of the data collected during the recent SI effort in Panama. An analysis of the calibration reference area data collected during the SI is presented. Topics explored include the probability of detection and false alarm ratio.

The UXO Detection Technology Findings, Results and Implementation Issues section summarizes the issues associated with implementing UXO detection technologies in Panama including navigation, false alarms, probability of detection (P_D), and site accessibility. Results of the detailed analysis of the SI transect data is provided as support for the findings.

The UXO Interrogation Process section provides an overview of the interrogation methodologies evaluated in this report. The initial report entitled, "Evaluation of UXO Detection and Interrogation Technologies For Use in Panama: Empire, Balboa West and Piña Ranges" was used as a guide for categorizing the UXO interrogation methodologies.

The UXO Interrogation Methodology Evaluation section included evaluations of manual and remote-controlled interrogation systems. An analysis of interrogation methodologies data collected during SI activities is presented as support.

The Environmental Impacts / Trade Off Analysis section examines the effects that implementation of such UXO detection technologies and interrogation methodologies might have on the environment. A discussion of the potential hazards to EOD or UXO removal personnel along with the potential UXO hazard level reduction is also discussed.

The Conclusion section provides conclusions from the EE effort conducted in Panama.

The intended use of this report is to provide all parties, including the GoP, involved in the range transfer process a technological evaluation of UXO detection technologies and interrogation methodologies for their applicability and usefulness in Panama. This report does not cover range transfer activities or any policy guidance related to the range turnover.

2.0 ENVIRONMENTAL CONDITIONS

This section discusses the environmental conditions associated with the Empire, Balboa West, and Piña Ranges. Environmental conditions are described because they are relevant to the evaluation of UXO detection technologies and interrogation methodologies. Specifically, this section describes the general environmental conditions of the Empire, Balboa West, and Piña Ranges, including the climate, topography and surface water drainage, surface and subsurface soils, vegetation, and endangered animal and plant species.

2.1 Climate

The Canal Area climate ranges from tropical savannah on the Empire and Balboa West Ranges (the Pacific side) to tropical wet in the Piña Range region (the Caribbean or Atlantic side). The tropical savannah climate is characterized by a distinct dry season from about January through April, while the tropical wet climate is characterized by heavy rains nearly year round (TNC and ANCON 1994). Between these regions is a tropical moist climate with one to two months of dry season. During the Pacific-side dry season, most of the upland soils dry and crack, and much of the grass and bush vegetation is susceptible to fire. The mean annual temperature and relative humidity for both the Pacific and Atlantic sides are about 26.7 C and 84 percent, respectively (USDOC 1996).

Precipitation in the Canal Area gradually increases from the Pacific side to the Atlantic side. March and April are the driest months, averaging about 1.6 centimeters (cm) of precipitation on the Pacific side and about 4.3 cm of precipitation on the Atlantic side. October and November are the wettest months, averaging about 24.4 cm of precipitation on the Pacific side and about 54.4 cm of precipitation on the Atlantic side. Measured over 37 years, the mean annual precipitation at Howard Air Force Base on the Pacific side is about 173 cm, while the mean annual precipitation at the town of Colon on the Atlantic side is about 348 cm (USDOC 1996).

2.2 Topography and Surface Water Drainage

The Canal Area has the lowest elevation on the Isthmus of Panama and is also one of the most hilly parts of Central America. Hills are numerous and range in height from about 50 to 335 meters above mean sea level. Elevations tend to increase with distance from the canal and are greatest near the boundaries of

Panama. Some slopes are too steep for cultivation and would severely erode if they were cleared and plowed without terracing. The most favorable areas for cultivation are along relatively flat riverbeds.

The conically shaped hills that characterize the Canal Area are spaced irregularly, reflecting regional differences in resistance to erosion and weathering. Areas underlain by soft rock, such as the area at the confluence of the Quebrada Conga and Rio Sierpe rivers in the Empire Range Main Impact Area, are characterized by broad valleys where streams have deposited layers of alluvial material. In areas underlain by harder rock with steeper gradients, such as the central portion of the Canal Area, streams have cut narrow, steep-walled canyons. Valleys widen and stream profiles flatten as drainage passes from the hard to relatively soft formations. Flat land is generally located in lowlands along the canal, such as the Pedro Miguel Locks area and the Range 5 area on the Empire Range, and in narrow strips along many of the coastal areas and stream channels.

Numerous rivers and streams drain the hilly terrain of the Empire, Balboa West, and Piña Ranges. Intermittent and seasonal streams consistent with local topographic and climatic characteristics also exist on the three ranges. Major streams on the Empire and Balboa West Ranges eventually flow into the Panama Canal, while major streams on the Piña Range flow into the Atlantic Ocean.

2.3 Surface And Subsurface Soils

Most of the soils in the Canal Area consist of clays, including alluvial soils that have a higher silt content than upland clays. Clay soils in the Canal Area are extremely friable as a result of severe, long-term weathering in a humid, tropical climate. Long-term leaching has removed most of the silica and lime, leaving iron and alumina. Upland soils are slightly acidic to alkaline. Poorly drained clay soils derived from tuffs and soils in the alluvial flats and depressions that have standing water for extended periods are acidic. The organic matter content of Panamanian soils ranges from about 2 to 8 percent and would probably not exceed 4.5 percent in the upland soils of the training ranges. More current sources of information regarding the organic matter content of soils in Panama were not found.

Empire and Balboa West Range soil types include Arraijan, Paraiso, Santa Rosa, and Bluefields clays. The Piña Range soil type is primarily Gatun clay. Arraijan clay, a reddish-brown or brownish-red clay, is the most extensive soil type on the Empire Range. The Arraijan clay is slightly crumbly or friable when moderately moist and is underlain by a 51- to 127-cm-deep, red clay of slightly friable or moderately stiff consistency, depending on its moisture content. On the Empire and Balboa West Ranges, a shallow phase of Arraijan clay occupies most slopes, ridge crests, and hilltops, while a thicker phase exists in lower and flatter areas. Destructive soil erosion occurs when sloped areas are cleared and rainwater forms gullies through the stiffer surface layer into the softer underlying material. The Arraijan clay bakes and cracks in the dry season and generally supports a lighter cover of vegetation than other soils in the area (USDA 1929).

The Gatun clay that characterizes the entire Piña Range is uniformly red, moderately friable clay with a 2.5-cm surface layer of brownish-red, friable clay. The Gatun clay ranges in depth from about 51 cm to about 2 meters and is underlain by soft, decomposed parent material. The Gatun clay occupies ridges and lowland areas; its drainage is described as good, and it shows no evidence of serious erosion (USDA 1929).

The clay soils of Panama are capable of holding a considerable amount of water in their pore space. Compared to sand- and silt-dominated soils, clay soils typically have more pore space and thus can hold more water. Reported soil water percentages (percent water by volume) are about 38 percent for the Arraijan clay and about 48 percent of the Gatun clay (USDA 1929). Actual soil water percentages are dependent on a number of factors, including the time of year, amount of vegetation, recent precipitation events, and other site specific factors. The clay soils of Panama are susceptible to landslides, especially in the steeply sloping areas and near excavations. The clay soils, when saturated, would have a high probability of sliding, particularly when the geological bedding plane is sloping or tilted down slope.

2.4 Vegetation

In 1992, TNC and ANCON began an ecological survey of Department of Defense (DoD) land in the Canal Area. The ecological survey was implemented in four phases. Phase 1 was a rapid ecological assessment designed to produce an overview of the ecosystem and biodiversity on the ranges. The rapid ecological assessment, which was conducted in 1994, classified and described vegetation based on field observations, satellite imagery, aerial photographs, site surveys, and literature reviews. Phases 2, 3, and 4 involved intensive field surveys to generate habitat and species inventories for all the DoD installations. Phase 2 focused on DoD lands on the east, Pacific side of the Panama Canal; Phase 3 focused on DoD lands west of the canal; and Phase 4 focused on the Caribbean side of the canal.

Results from the rapid ecological assessment indicate that most portions of the Empire, Balboa West, and Piña Ranges are densely vegetated. The exceptions are areas where (1) range maintenance practices such as mowing and controlled burning take place in the immediate vicinity of target and impact areas and (2) encroachment in the form of slash-and-burn farming has occurred.

The rapid ecological assessment identified eight vegetation classes in the Canal Area: (1) mangrove swamp; (2) marshes; (3) grasslands, pastures, and crops; (4) shrub land; (5) swamp forest; (6) deciduous forest; (7) semideciduous seasonal forest; and (8) evergreen seasonal forest. Of these, the semideciduous and evergreen seasonal forests dominate the Empire, Balboa West, and Piña Ranges. Aside from rather small, isolated pockets of grassland, pasture, and cropland, the other vegetation classes are absent from the ranges. The rapid ecological assessment also revealed that the area has high biodiversity and potentially contains new plant species. Moreover, the deciduous and semideciduous seasonal forests are considered rare in Central America.

The deciduous, semideciduous seasonal, and evergreen seasonal forests are upland forests and are distinguished by their degree of leaf loss during the dry season. More than 75 percent of the deciduous forest, upper-canopy trees lose their leaves in the dry season; between 25 and 75 percent of the semideciduous seasonal forest, canopy trees lose their leaves in the dry season; and less than 25 percent of the evergreen seasonal forest, canopy trees lose their leaves during the dry season (TNC and ANCON 1994). Many subclasses of vegetation with significant variation of species exist within these upland forests.

Semideciduous seasonal forest covers about 91 percent of the Empire Range. Two subclasses of semideciduous forest are present: medium-statured and tall-statured. These forests feature thick vegetative canopies ranging from 15 to 50 meters in height. Medium-statured forest covers most of the area, especially near roads and a pipeline that crosses the Empire Range. The extent of the medium-statured forest is attributed to timber extraction and general forest clearing activities that took place early in this century. Tall-statured forest generally exists away from access roads and is frequently associated with steep slopes. The tall-statured forest represents a mature, relatively undisturbed tropical ecosystem. The greatest concentrations of tall-statured forest are found in the north and northeast parts of the Empire Range near the Balboa West Range. Some of the most common species in this forest are the wild cashew (*Anacardium excelsum*), yellow wood (*Terminalia amazonia*), and kapok tree (*Ceiba pentandra*) (TNC and ANCON 1994).

Grasslands cover about 9 percent of the Empire Range and are located primarily in the southwest near the towns of Arraijan and Nuevo Emperado. Grasslands also exist in the Main Impact Area near Cerro Sierpe and along roads. Grasslands are dominated by Vietnam grass (*Saccharum spontaneum*) and Guinea grass (*Panicum maximum*), which are tall (up to 2 meters), thick-growing grasses. In addition, migrant farmers from nearby settlements have planted crops such as corn, rice, cassava, and yams in the forest clearings, and grasslands in these areas are the result of recent deforestation.

Semideciduous seasonal forest covers about 96 percent of the Balboa West Range, and grasslands mixed with pastures and cropland cover the rest of the range. Tall and medium statured semideciduous seasonal forests are distributed throughout the Balboa West Range, with the medium-statured forest covering most of the range. Some of the dominant trees of this forest are West Indian elm (*Luehea seemannii*), Ecuador laurel (*Cordia alliodora*), and wild plum (*Spondias mombin*).

Grasslands that occur along roads on the Balboa West Range are dominated by Vietnam grass. Grasslands mixed with pastures and cropland exist in the southwest corner of the Balboa West Range near Huile as a result of disturbances caused by Panamanians cutting and burning the forest to plant subsistence crops.

Semideciduous seasonal forest and evergreen seasonal forest cover about 98 percent of the Piña Range. Evergreen seasonal forests differ from the semideciduous forests by keeping more of their leaves through the dry season, which is very short on the Atlantic side. Most of the Piña Range consists of relatively pristine, mature, tall-statured evergreen forest and ecosystems that have not been significantly disturbed by human activity. Medium-statured evergreen seasonal forest, which has been more disturbed than the tall-statured forest, is found in the extreme northeast and northwest parts of the Piña Range and near La Treinticinco. The most common evergreen forest species on the range include the kapok tree, male trumpet tree (*Pourouma guianensis*), star apple tree (*Chrysophyllum cainito*), and suicidal tree (*Tachigalia versicolor*) (TNC and ANCON 1994).

2.5 Plant and Animal Species

Ecological assessments conducted in Panama revealed that diverse plant and animal species exists on DoD land in the Canal Area. In all, nearly 900 different species of plants and over 740 species of animals were found including some of, which are globally imperiled, or nationally imperiled, or protected under Panamanian Law. Table 2-1 summarizes the vast diversity of plant and animal types for the areas, which include the Empire, Balboa West and Piña Ranges.

Table 2-1 Plant And Animal Species Found On Areas Encompassing The Empire, Balboa West And Piña Ranges

Area	Number of Plant Species	Number of Mammal Species	Number of Bird Species
Horoko, Empire Range and Balboa West Range	881 91 of which are globally imperiled	83 13 protected by Panamanian Law	224 5 protected by Panamanian Law
Fort Sherman, Piña Range and Naval Security Group Activity, Galeta Island	809 114 of which are globally imperiled	60 16 protected by Panamanian Law	213 7 protected by Panamanian Law

Several of the animal species protected by Panamanian law are listed below.

Wood stork (*Mycteria americana*)

Peregrine falcon (*Falco peregrinus*)

Brown pelican (*Pelecanusoccidentalis*)

Titi monkey (*Saguinus oedipus*)

Ocelot (*Felis pardalis*)

Spider monkey (*Ateles geoffroyi*)River otter (*Lontra longicaudis*)

Jaguar *(Panthera onca)*

3.0 SURFACE vs. SUBSURFACE UXO CONCENTRATIONS

Ordnance items that do not detonate upon impact and are dud may penetrate the soil and become buried. Therefore, in order to fully describe UXO concentrations a depth component must be added to the longitude and latitude components. Ordnance penetration depths depend upon characteristics of the ordnance item deployed and the properties of the soil being impacted. The major characteristics that effect penetration depth include ordnance weight, shape, material, velocity, and angle of impact into the soil. Studies have been conducted over the years on ordnance penetration depths and soil conditions. An extensive study which offers generalized solutions that produce estimates for maximum expected UXO penetration depths was developed by the Soils Dynamics Laboratory at the U.S. Army Corps of Engineers Waterways Experimental Station (WES). Results of the study have been published in an U.S. Army Technical Manual (TM) entitled *Fundamentals of Protective Design For Conventional Weapons,* TM 5-855-1. The theory and formulas derived from TM 5-855-1 have also been incorporated into a software program which has the capability of estimating the maximum probable theoretical depth of penetration of ordnance items based upon the factors listed above.

The theories and formulas derived in TM 5-855-1 are not presented here but the results are. The results are presented in Table 3-1 and cover the majority of the ground deployed ordnance items that were reportedly used in Panama. Knowing the maximum probable depth of penetration allows for a direct comparison between the maximum depth of possible UXO concentrations and the capability of a sensor to detect the buried UXO within an area of concern. In some cases even the most promising sensor will not be able to detect items buried at their maximum possible penetration depth (see Section 6). Therefore, it would be impossible to clear 100% of the UXO in a single sweep from an area because of the limited detection range of the sensor.

The safe overburden is also presented in Table 3-1 and is the amount of overfill that is required to contain the effects of a blast of a buried UXO of that particular type, for example, if a buried UXO were to detonate at a depth deeper than the safe overburden, the blast would not effect the surface.

Table 3-1 UXO Penetration Depths

Ordnance Type	Gross Ordnance Weight		Estimated Maximum UXO Penetration				Safe Earth Fill (overlay thickness)		Explosive Weight		Ordnance Body Weight	
			sandy soil		clayey soil							
	lbs.	kgs.	feet	meters	feet	meters	feet	meters	lbs.	kgs.	lbs.	kgs.
20mm	0.56	0.25	1.0	0.305	3.0	0.914	0.9	0.274	0.29	0.13	0.56	0.25
60mm	3.52	1.60	1.0	0.305	3.0	0.914	2.6	0.792	0.42	0.19	3.52	1.60
2.36"	19.40	8.81	1.0	0.305	3.0	0.914	2.8	0.853	1.82	0.83	19.40	8.81
66mm	2.35	1.07	2.0	0.610	4.5	1.372	3.1	0.945	0.67	0.30	2.35	1.07
37mm	1.61	0.73	2.5	0.762	5.0	1.524	2.6	0.792	0.11	0.05	1.61	0.73
40mm (AA)	1.98	0.90	2.5	0.762	5.5	1.676	1.8	0.549	0.14	0.06	1.98	0.90
81mm	9.22	4.19	3.0	0.914	6.5	1.981	5.7	1.737	2.05	0.93	9.22	4.19
2.75" rocket	8.90	4.04	3.5	1.067	7.5	2.286	6.0	1.829	2.32	1.05	8.90	4.04
57mm	5.29	2.40	4.0	1.219	8.5	2.591	2.9	0.884	0.55	0.25	5.29	2.40
4.2" mortar	27.07	12.29	4.0	1.219	8.5	2.591	6.9	2.103	7.80	3.54	27.07	12.29
75mm	10.14	4.60	4.5	1.372	9.5	2.896	4.8	1.463	1.49	0.68	10.14	4.60
105mm	31.80	14.44	5.5	1.676	11.5	3.505	6.9	2.103	5.08	2.31	31.80	14.44
106mm recoiless	17.55	7.97	5.5	1.676	10.5	3.200	6.9	2.103	7.72	3.50	17.55	7.97
3.5"	9.00	4.09	5.5	1.676	10.5	3.200	4.3	1.311	1.88	0.85	9.00	4.09
76mm	14.15	6.42	6.0	1.829	12.0	3.658	4.0	1.219	1.46	0.66	14.15	6.42
3"	13.50	6.13	6.0	1.829	12.0	3.658	3.5	1.067	0.74	0.34	13.50	6.13
4.5"	42.50	19.30	6.5	1.981	13.0	3.962	6.4	1.951	4.30	1.95	42.50	19.30
90mm	11.24	5.10	7.0	2.134	13.0	3.962	4.5	1.372	2.15	0.98	11.24	5.10
152mm	95.92	43.55	7.5	2.286	15.0	4.572	6.5	1.981	9.50	4.31	95.92	43.55
5"	70.00	31.78	8.0	2.438	16.5	5.029	8.3	2.530	7.59	3.45	70.00	31.78
155mm	94.60	42.95	8.5	2.591	16.5	5.029	8.7	2.652	15.40	6.99	79.20	35.96
120mm	31.20	14.16	9.0	2.743	17.0	5.182	7.0	2.134	6.59	2.99	31.20	14.16

As discussed in Section 2 of this report, the Panama soil is mostly clayey, therefore, the maximum probable ordnance penetration depths that apply to Panama are found in the clayey soil column that is highlighted in Table 3-1. Therefore, UXO can be found up to the maximum penetration depth of their particular type, which may not be detectable due to the limited detection ranges of UXO detection technologies. Section 4 of this report covers the process in which UXO surface and subsurface are found. Section 6 of this report covers specific detector evaluations that were conducted in Panama as part of the Engineering Evaluation effort.

4.0 UXO DETECTION PROCESS

Surveying a site that is potentially contaminated with UXO is a methodical process, which involves several steps including proper site preparation and surveying procedures, each having logistical requirements. A brief description of each step in the UXO survey process is included below.

4.1 Site Preparation

In order to safely and effectively search for UXO, the area must be accessible and clear of vegetation and overgrowth because they can limit the visibility in an area and mask UXO. Because of the risk associated with UXO, EOD, or explosive operations personnel cannot safely enter an impact area unless the area is clear of visual obstructions. There are several methods of removing the overgrowth including controlled burning, mechanized machinery or remote controlled or tele-robotic machinery. Site accessibility and environmental constraints on implementing technologies are explored further in Section 6 of this report. After the site is cleared of vegetation and overgrowth, the boundaries of the survey area must be marked and data control points or area reference markers must be established.

Once the surface has been cleared of vegetation and overgrowth and the survey boundaries have been established, the area is swept for surface UXO and debris. UXO on the surface present a hazard to the survey team in the area and must be removed or destroyed in accordance with proper EOD procedures. Range debris and other conductive materials foreign to the natural environment may effect the performance and results of the detectors and are usually removed whenever possible from the survey area.

4.2 Survey Procedures

The exact survey procedures used are a function of the specific sensor used, mode of operation and the local environmental conditions of the survey area. Certain sensors require a reference station or background monitor. The Geonics G858 total field magnetometer array (see Section 5.3.1), for example, requires a reference base station to measure the diurnal drift in the earth's magnetic field for that particular area. The drift data is used to correct the magnetic data collected by the sensor head by compensating for natural magnetic drifts in the earth's magnetic field. Other system configurations do not require additional reference stations or background monitors but require fine-tuning in terms of sensor height adjustments or sensor response adjustments to increase the probability of detecting anomalies in that local environment. Sensor response adjustments are often times referred to as sensitivity adjustments. These adjustments allow for the detector's response to be adjusted for various intended targets and background noise scenarios. For example, if the intended targets were large shallow items and the background noise was considerably high, the sensitivity would be set very low to washout the high background noise and to pick up the larger response expected from the target.

Once the area has been prepared and the sensor has been calibrated for the local environment, the survey can begin. The survey itself involves moving the sensor across the area in a pre-determined fashion to capture data over the entire survey area. Sensors can be mounted on various platforms including man portable, vehicular and airborne. Section 6 of this report covers the applicability of each platform in the Panamanian environment. Man portable detectors are usually deployed in lanes that run the length or width of the survey area. Each lane is surveyed until the entire area is covered. The lane spacing depends upon the swath width of the sensor, the environment and the intended target. Lane spacing becomes important because lane spacing too wide may contribute to targets being missed by the sensors. Some lanes are configured in an overlapping fashion or are bi-directional to provide additional data. The location of the detector must also be known at all times in order to correlate the survey data with a position on the ground. Several methodologies are available to record position data including global positioning systems (GPS), radio beacons, tick wheels, and devices that measure time, velocity and distance. After the sensor and position data is collected the last step in the survey process involves processing the data to determine the locations and strengths of the targets. There are many different ways and methodologies for processing the data, which often provide the user with an estimate of the target size and depth.

Certain detectors can be used in the "mag and flag" or "treasure hunt" mode, which eliminates the need for position tagging the data. The "mag and flag" mode involves placing flags or markers everywhere an anomaly is located as the operator progresses along a survey line. The disadvantages of using the "mag and flag" mode is that there is usually an increase in field survey time and that the data is not post processed. However, the targets are identified and marked immediately in the field therefore, eliminating the need for target re-location. Survey modes are discussed further is Section 8 of this report.

4.3 Logistics Requirements

In order to survey an area for UXO there are several logistical items that are needed in order to complete the operation. The exact types and amounts of items needed varies with the technologies and methodologies implemented but most share common items such as power sources (generators or batteries), computers for data processing, geodetic monuments or known survey reference points.

5.0 UXO DETECTION TECHNOLOGIES

This section of the report provides a quick overview of the UXO detection technologies that were used in the EE effort in Panama. The results of the initial technology evaluation conducted last year are included as background in Section 5.1. Also included in this section of the report is a brief overview of the theories involved with each category of UXO detection technologies along with a description of each specific detector evaluated along with the method of employment.

5.1 Background: Initial UXO Detection and Interrogation Technology Evaluation

UXO detection technologies for use in Panama were initially evaluated in the technology evaluation report where UXO detection refers to locating and potentially identifying surface and subsurface anomalies. This preliminary evaluation of UXO detection and interrogation technologies for use in Panama was conducted based on the effectiveness and implementability of the technologies. Five categories of UXO detection sensors were evaluated in that report: passive magnetometry, active electromagnetic (EM) induction, ground-penetrating radar (GPR), infrared (IR), and a multisensor approach (which is a combination of the other four sensor types). UXO detection sensors were further evaluated according to the following operational platforms: airborne, vehicle-towed, and man-portable. Two basic criteria were used, in the initial report, to evaluate UXO detection technologies: effectiveness for the intended purpose and implementability. These criteria were defined as follows:

- **Effectiveness:** the ability of the technology to detect or interrogate UXO.

- **Implementability:** the technical feasibility (that is, the capability of the technology to perform at the site) and logistical and support requirements of operating the UXO detection or interrogation technology.

The results from that initial assessment of UXO detection and interrogation technologies potentially applicable for use on the ranges in Panama are listed in Table 5-1.

Table 5-1 Capabilities, Limitations, Effectiveness And Applicability Off UXO Detection Technologies In Panama From The Initial UXO Technology Evaluation

Category	Technology	Capabilities and Limitations	Effectiveness	Potentially Applicable in Panama
UXO Detection Sensors	Passive Magnetometry	•Detects only ferromagnetic, iron-based metal objects	High to Medium	Yes
	Active EM Induction	•Detects all types of metals •Potentially unsafe if electronically fuzed ordnance is present	Medium	Yes
	GPR	•Detects metallic and nonmetallic objects •Severely limited by vegetation and wet soils •Potentially unsafe if electronically fuzed ordnance is present	Low to Not Effective	No
	IR	•Detects only surface ordnance •Limited by vegetation •No field-proven systems available	Low to Not Effective	No
	Multisensor	•Collects and combines data from two or more sensors •Higher P_D and higher FAR* than single-sensor systems	High to Medium	Yes

* FAR = False Alarm Ratio (see Section 7)

In addition to evaluating technological categories, the report also evaluated detection platforms including airborne, vehicle-towed and man-portable. From the initial preliminary evaluation it was concluded that airborne detection platforms would not be effective in Panama. The preliminary assessment also concluded that vehicle-towed UXO detection systems would be effective and implementable in areas on the ranges that are currently accessible to vehicles or that would be accessible with limited road construction. The preliminary assessment also concluded that man-portable UXO detection systems would be effective and implementable in many areas of the ranges in Panama, but not in steeply sloping or very densely vegetated areas, which would severely hinder the employment of any UXO detection technology.

5.2 Site Investigation Detection Technologies and Platforms

The preliminary evaluation conducted in the UXO assessment report was used as the basis for selecting specific UXO detection technologies for the EE effort. Two categories of technologies, GPR, and IR, were ruled out from the start because they would not be effective in the Panamanian environment. The three remaining categories that are potentially promising and effective based on the preliminary evaluation included passive magnetometry, active EM induction systems, and a multi-sensor approach. Three specific technologies from the first category, passive magnetometry, were selected for the EE: a cesium vapor magnetometer system using a Geometrics™ G858 magnetometer, the Schonstedt™ GA-72CV magnetic locator, and the Ferex 4.021 (Mk 26) ferrous locator. Three active EM systems were selected for the EE effort including the Geonics™ EM 61 time domain metal detector, the Vallon MW 1630 (Mk 29) all metals locator, and the White 6000/Di Pro SL all metals locator. The third category, a multi-sensor approach, is merely a combination of two or more sensors from the various categories and is covered in Section 7 of this report.

There is a distinct difference between a passive sensor and an active sensor. Passive sensors detect signals, but do not generate any signals themselves while active sensors generate signals and measure the associated responses. This distinction is important because in rare cases certain UXO items may be susceptible to the signals produced by an active sensor thus causing it to detonate.

UXO detection technology platforms utilized under this effort were selected based upon results of the initial preliminary evaluation. From the preliminary evaluation it was determined that airborne platforms would not be effective in Panama and vehicular platforms would only be applicable in limited areas. Therefore, only man-portable platform configurations were evaluated.

Background theory and a description of each technology category, along with the specific sensors selected from each category, are provided in Sections 5.3 and 5.4 for passive magnetometry and EM induction categories respectively.

Several specific technologies from the two promising technology categories, passive magnetometry and EM sensors, were evaluated in man-portable configurations in Panama to refine and/or confirm the results of the initial report.

5.3 Passive Magnetometry

The earth has a natural magnetic field that resembles a large bar magnet near its center. The intensity of the field is a function of the density of the flux lines which is approximately twice as intense in the polar region as in the equatorial region, or approximately 60,000 and 30,000 gammas (1 gamma = 1 nanoTesla (nT)) respectively.

Ferrous materials also have a magnetic field associated with them. The measured intensity of the field is dependent upon many factors including the size, shape, and type of material. Sensors used to measure the intensity of magnetic fields are called magnetometers. Since most ordnance items contain some ferromagnetic material, the sensor technology principles are valid for locating most buried UXO. The exact amount and type of ferromagnetic material in each ordnance type depends upon the particular design of the item.

Although each specific passive magnetometer is different most detectors have the following components: sensor head(s), a power supply, a computer data system, and a navigation system or a means to record locations of detected anomalies. Three specific passive magnetometers were evaluated including a cesium vapor magnetometer system using a Geometrics™ G858 magnetometer, a Schonstedt™ GA-72CV magnetic locator, and a Ferex 4.021 (Mk26) ferrous locator. A description and method of employment for each system is provided below.

5.3.1 Geometrics™ G858 Magnetometer

The Geometrics G858 is a cesium vapor magnetometer that measures the total magnetic field intensity at the sensor's location. Detection of ferrous anomalies is accomplished by observing rapid spatial changes of the earth's ambient magnetic field. The earth's natural magnetic field, which varies from 30,000 nanoTesla (nT) around the equator to 60,000 nT around the poles, is disturbed by local sources of magnetic fields such as those given off by buried UXO that have ferrous content. These abrupt changes are detected in the G858 and presented to the operator by either an increase or decrease in the nT readings on a digital display. An audio indicator also alerts the operator to any changes in the earth's magnetic field. When feasible, systematic sampling or surveying using defined grids and the use of a reference base station increase the detection capabilities and sensitivity of the magnetometer. The exact number of readings taken for a particular survey is dependent upon the sampling frequency and speed the sensor is moving across the area. A typical survey of a 10 by 10-meter area would involve 1,000 – 5,000 readings depending upon the sample separation. Survey or grid readings are evaluated with respect to each other using software algorithms and other data processing techniques. The G858 system is shown in Figure 5-1.

Figure 5-1 G858 Instrument

Method of Employment

The G858 can be deployed as a hand held unit which the operator carries steady while walking forward at a constant speed (used in the survey mode) or deployed in a sweeping motion over the suspect area in the "mag and flag" mode (targets are marked as soon as they are found). The height of the sensor off the ground is between 6 and 12 inches depending upon the background noise and environmental conditions at the survey site. When the locator comes within range of a ferrous object, a higher frequency is emitted from the speaker corresponding to an increase or decrease in the local magnetic field. The digital display of the G858 system provides the user with the strength of the local magnetic field. After a target is detected, the locator is moved back and forth to find the area effecting the signal including the signal peaks. The signal behavior can be used to estimate the size and depth of the particular anomaly.

5.3.2 Schonstedt™ Magnetic Locator (Model GA-72CV)

The Schonstedt GA-72CV detects the local magnetic field using two individual sensors oriented one on top of the other 20 inches apart. The configuration is commonly referred to as a gradiometer because the detector locates anomalies by the magnitude of the difference in the responses of each sensor. The output of the Schonstedt is an audio response through a built-in loudspeaker on this particular model. When the first sensor's readings match that of the second sensor the audio output puts out an idling response. As the detector is positioned over a ferromagnetic anomaly the reading from the lower sensor will be different from the reading in the upper sensor. As a result of the difference in readings the pitch of the audio output changes. The larger the difference, the greater the difference in the pitch. The unit has a sensitivity adjustment feature which allows the operator to adjust the idle and output response range of the system. The detector is a hand held unit weighing approximately 1.36 kgs, with a length of about 110cm. Standard "C" batteries power the unit.

Method of Employment

The detector is a hand held unit which the operator waves in a sweeping motion over the suspect area. The sensor is held from the ground at a height of 6-12 inches depending upon the background noise and local environmental conditions at the survey site. When the locator comes within range of a ferrous object, a higher frequency is emitted from the speaker. After a target is detected, the locator should be held vertically and moved back and forth in an "X" pattern to find the area effecting the signal including the signal peaks. The signal behavior can be used to estimate the size and depth of the particular anomaly.

The height and sensitivity setting of the instrument can also be adjusted to estimate the target size and depth. For example, signals that drop off sharply when the instrument is raised a couple of inches off the ground, or when the sensitivity is slightly adjusted, are probably the result of a very small target close to the surface such as a bolt or other small ferrous object. Once the target has been estimated, its location is marked and surveyed for interrogation. Figure 5-2 shows the Schonstedt instrument being employed.

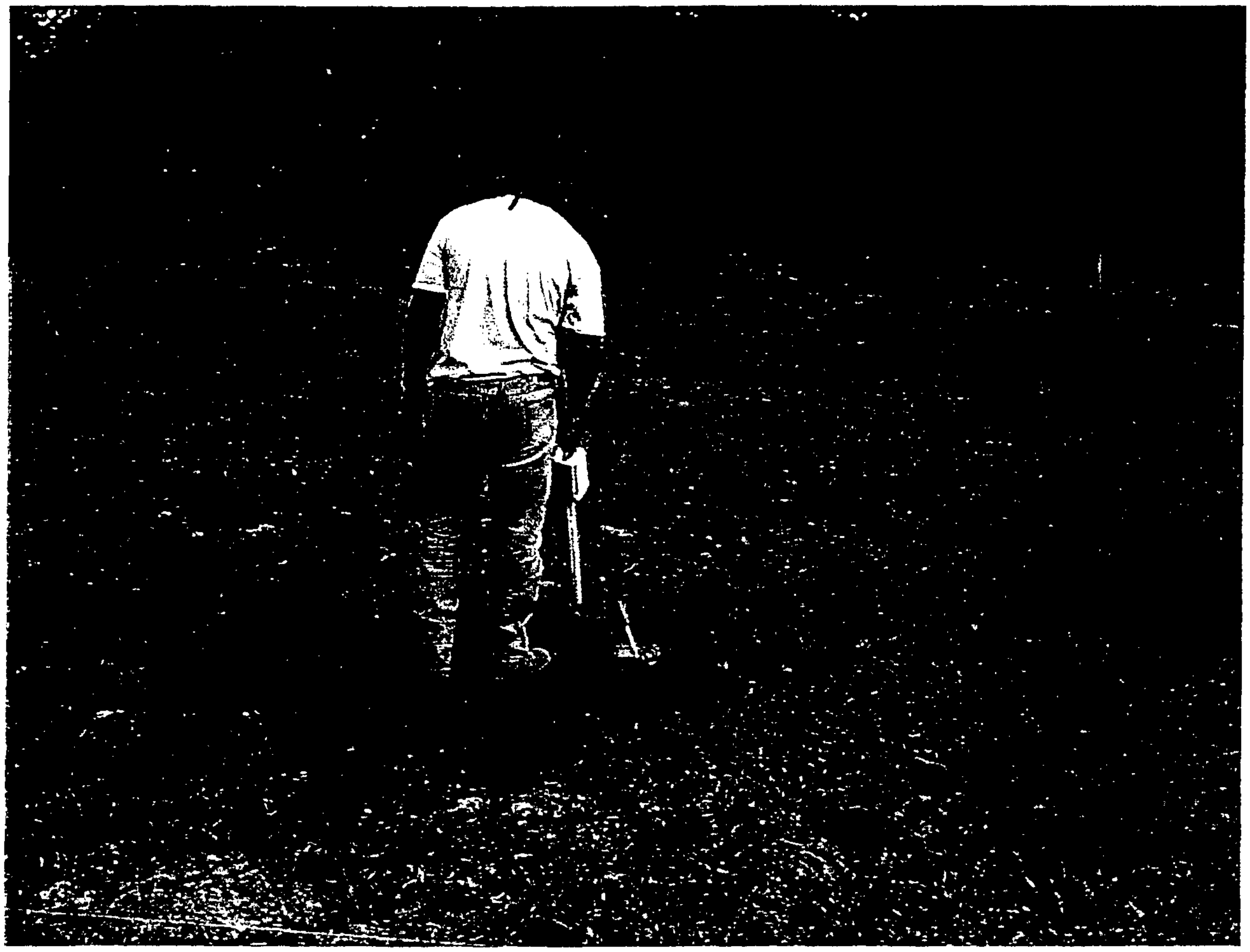

Figure 5-2 Schonstedt Instrument

5.3.3 Ferex 4.021 (Mk 26) Ferrous Locator

The Ferex 4.021 detector (Mk26) is a magnetometer, which has two sensors, oriented one on top of the other in a gradiometer configuration. The detector locates anomalies by the magnitude of the difference in the responses of each sensor. The Ferex 4.021 is a common UXO detection device that is used by many U.S. Military EOD units and is often referred to as the Mk26. The Ferex 4.021 has two outputs including a quantitative nT (1 nT = 1 gamma) reading and an audio response through a built-in loudspeaker. When the first sensor's readings match that of the second sensor, the sensor indicator needle reads 0 nT while the audio response has a constant idling output. As the detector is positioned over a ferromagnetic anomaly, the reading from the lower sensor will be different from the reading in the upper sensor. As a result of the difference in readings, the needle moves indicating the magnitude of the response (nT) while the pitch of the audio output increases. The larger the difference, the higher the pitch. The unit has a sensitivity adjustment feature which allows the operator to adjust the idle and output response range of the system. The detector is a hand held unit weighing approximately 4.5 kgs and is powered by standard size "C" batteries. Figure 5-3 shows the MK 26 instrument being used.

Figure 5-3 Operational Photo Of MK26

Method of Employment

The detector is a hand held unit that the operator carries over the suspect area perpendicular to the ground, and at a constant height between 6-12 inches depending upon the background noise and local environmental conditions at the survey site. When the locator comes within range of a ferrous object, the gamma indicator needle moves and a higher frequency is emitted from the speaker. The magnitude and behavior of the response can be used to estimate the size and depth of the particular anomaly according to the manual.

5.4 Electromagnetic Induction for Ordnance Location

EM induction systems are active sensors, which transmit electronic current or signals into the ground. When the signal contacts a metallic item it induces eddy currents into that item. The eddy currents cause a time-varying secondary EM field. The locator then either measures components of the secondary induced EM field or the difference between the electrical conductivity of the soil and the buried object. The characteristics of the measured response are used to estimate the size and depth of the target. Three active EM systems, were selected for the EE effort including the Geonics™ EM61 time domain metal detector, the Vallon MW 1630 (Mk 29) all metals locator, and the White 6000/Di Pro SL all metals locator. A system description and method of employment for each is included below.

5.4.1 Geonics™ Electromagnetic (EM) 61 Time Domain Metal Detector

Two man-portable configurations of the Geonics EM61 were used in Panama for the SI and EE efforts: the EM61 cart configuration and the EM61 HH configuration, both of which use the same electronics backpack. The significant difference between the cart and hand held mode being the antenna configuration. The cart configuration has one transmit coil and one receive coil each measuring 1 meter square which is attached to two wheels and is pulled behind the operator. The coils are mounted in a box like configuration 40 cm apart, one on top of the other. The transmit coil sends a pulsed primary magnetic field into the earth which causes eddy currents in nearby metallic objects. The eddy current decay, whose rate is determined by the size and composition of the material, produces a secondary magnetic field, which is measured by the receiver coil. The complete system includes the coils, an electronics package, and a data logger. The EM61 HH configuration is a scaled down version of the EM61 cart mode using a different antenna. The coils are positioned on a hand held wand and are smaller in size. The system uses the same electronics backpack and data logger as the EM61 cart mode. On the hand held unit, data is collected twice at different times, an early response at 1 time gate and a second response at 2 time gates. The EM61 cart and EM61 HH hand held systems are shown in Figures 5-4 and 5-5 respectively.

Figure 5-4 EM61 In The Cart Configuration

Method of Employment

Again, only man-portable configurations were considered for the SI and EE efforts. The two man-portable EM61 configurations evaluated were the cart model and the smaller hand held model. The cart configuration requires the user to pull a cart behind him over the survey area. As the cart is pulled over the area at an even rate, walking speed, data is captured in the data logger pack electronically. The smaller EM61 HH unit is held in front of the surveyor as the area is traversed. The detector head is held parallel to the ground at a distance of 6-12 inches depending upon the level of background noise. As the area is surveyed the data logger collects sensor data. The EM61 HH can also be used with optional wheels that are attached to the handle which allows the EM61 HH to be employed like a small cart (see Figure 5-6).

Figure 5-5 EM61 Hand Held Mode Without Wheels

The EM61 HH like many other detectors can be used in several different survey modes including data collection with post processing or "mag and flag". In Panama, the EM61 HH was used in the data collection with post processing mode on the calibration reference area and in the "treasure hunt" or "mag and flag" mode on the transect surveys. The "mag and flag" mode is a standard mode that involves placing flags or markers at every suspect UXO spot as the operator progresses along a survey. The modes of operation are discussed further in Section 8 of this report.

Figure 5-6 EM61 Hand Held Mode With Optional Wheels

5.4.2 Vallon MW 1630 (Mk 29) All Metals Locator

The Vallon MW 1630 detector is an all metals EM sensor that is a common UXO detection device that is used by many U.S. Military EOD units and is often referred to as a Mk29. The detector has four major components: a search coil, a handle, an electronics unit, and a headset. As the search coil receives a response from a metallic object, an acoustic signal is generated through the systems earphones. The stronger the signal, the higher the pitch of the audio output. The unit has a sensitivity adjustment feature which allows the operator to adjust the idle and output response range of the system. The detector is a hand held unit weighing approximately 3.4 kgs. and is powered by standard size "C" batteries. Figure 5-7 shows the MK 29 instrument in use.

Figure 5-5 MK 29 Instrument

Method of Employment

The detector is a hand held unit that the operator carries over the suspect area perpendicular to the ground and at a constant height between 6-12 inches depending upon the background noise and environmental conditions at the survey site. As soon as the measuring range of the detectors search coil is affected by a metallic object, an acoustic signal is generated through the earphones. The magnitude and behavior of the response can be used to estimate the size and depth of the particular anomaly.

5.4.3 White 6000/Di Pro SL All Metals Locator

The White 6000/Di Pro SL detector is an all metals EM sensor and is a commercially available system used by many treasure hunters and survey hobbyists. The detector has three major components: a search coil, a handle, and an electronics unit. As the search coil receives a response from a metallic object, an acoustic signal is generated through the system's speakers and the strength indicator (needle) moves to indicate the magnitude of the response. The unit has a sensitivity adjustment feature which allows the operator to adjust the idle and output response range of the system. The detector is a hand held unit weighing approximately 3.0 kgs. and is powered by standard "C" size batteries. Figure 5-8 shows the White Di Pro SL instrument in use.

Figure 5-6 White Instrument

Method of Employment

The detector is a hand held unit (identical in employment to the Mk29) that the operator sweeps in front of him from side-to- side keeping the loop close to the ground throughout the swing. Each pass of the loop should be done slowly (one-half to two seconds in each direction). Walking forward slowly, each step should be no greater than half the length of your foot. Each pass of the loop should overlap the last by at least half the length of the loop. The loop should be kept steady close to the ground at all times. As soon as the measuring range of the detector's search coil is affected by a metallic object, an acoustic signal is generated and the response needle moves. The magnitude and behavior of the response can be used to estimate the size and depth of the particular anomaly.

6.0 UXO DETECTOR EVALUATIONS

One of the main objectives of the effort was to provide an assessment of UXO detectors in the Panamanian environment. However, actual sensor performance is difficult to predict without a thorough understanding of the intended targets and the environment the sensor is being asked to operate in. It is therefore necessary to establish a rough baseline of performance for each sensor considered in an ordnance sweep to determine the following parameters: (1) the maximum target to sensor detection range (depth or Z spatial component); (2) the minimum spacing to be used in a geophysical survey to ensure that the signal produced by the presence of the ordnance fall within the detectors field of view (longitude / latitude or X and Y spatial components); (3) the proper detector to use given specific ordnance targets; and (4) geophysical constraints such as ambient magnetic noise, terrain, and vegetation. To establish a baseline for the first two parameters two separate evaluations were conducted in Panama. The two evaluations included the maximum detection range evaluation, and the sensor field of view evaluation, which are covered in this section of the report. The third and fourth parameters are explored further in Section 8 of this report. The purpose, procedure, results and conclusions for each of the maximum detection range and the sensor field of view evaluations are presented in below.

6.1 Maximum Detection Range Evaluation

6.1.1 Purpose

The purpose of this evaluation was to examine maximum target to sensor detection range for given specific ordnance types. The maximum target to sensor range, or detection range, can then be compared to the maximum probable penetration depths (Section 3 of this report) of the ordnance to determine the if the sensor is capable of potentially locating every target up to its maximum penetration depth.

6.1.2 Procedure

A grid was set up on Empire range measuring two meters square with the center point defined in Cartesian coordinates as 0,0. The area was then swept clean of any sources of magnetic or conductive material (noise) that could influence the test. An ordnance target was then placed on the surface of the ground over the point 0,0 with the longitudinal axes facing north. Each of the four detectors (Schonstedt, Mk 29, Mk 26, and White) were then positioned directly over the target and were moved, in a vertical direction upward until the sensor could no longer detect the presence of the item. At that point, the distance from the center of the target to the bottom of the sensor head was measured. The distance represents the maximum detection distance for that particular sensor and target combination. A conservative approach was used to ensure that distances obtained represented an absolute maximum by setting the test parameters including detector sensitivity and signal attenuation accordingly. To accomplish this each sensor was set at maximum sensitivity so that each sensor was operating in its most sensitive range. In addition the evaluation was conducted in air because soil would tend to attenuate the signal from buried ordnance, thus decreasing the detection range. The amount of attenuation is a function of the properties of the soil and is not specifically covered in this report. Therefore, the distances represent the absolute maximum distance (best case) detectable for that sensor. The procedure was repeated for each sensor on each of the four test targets. A description of the test targets can be found in Appendix A of this report. Figure 6-1 shows the Schonstedt instrument being tested.

Figure 6-1 Maximum Detection Test Using Schonstedt

6.1.3 Results

Results of the maximum detection range evaluation are presented in Table 6.1 below: For comparison purposes the maximum penetration depth and depth of reliable detection is included which is discussed further in the maximum detection range conclusions. The data is also provided in graph form as Figure 6-2.

Table 6-1 Maximum Detection Range In Air

Target (Appendix A)	Schonstedt	Mk 26	Mk 29	White	EM61 HH	G858	Reliable Detection Depth	Max Penetration
37mm projectile	65	70	45	34.5	41	60	30.5	152.4
60mm mortar	48	53.5	50	38	31	55	61	91.4
81mm mortar	59	87	56	50	51*	74*	NA	NA
105mm projectile	75	184	64	58	60*	100*	121.9	350.5

*Data was extrapolated All Values in centimeters

The greatest detection range for each particular target has been highlighted. The table shows that the Mk 26 gradiometer has the greatest detection range, particularly for larger ordnance items such as the 105mm. The gradiometer detectors (Schonstedt & Mk 26) were consistently better than the active EM detectors (Mk 29 & White).

Table 6-1 and Figure 6-2 show that none of the sensor technologies are capable of detecting ordnance near their maximum penetration depth, even under "best case" or ideal conditions. In reality actual sensor performance experienced in the field will be worse in most cases.

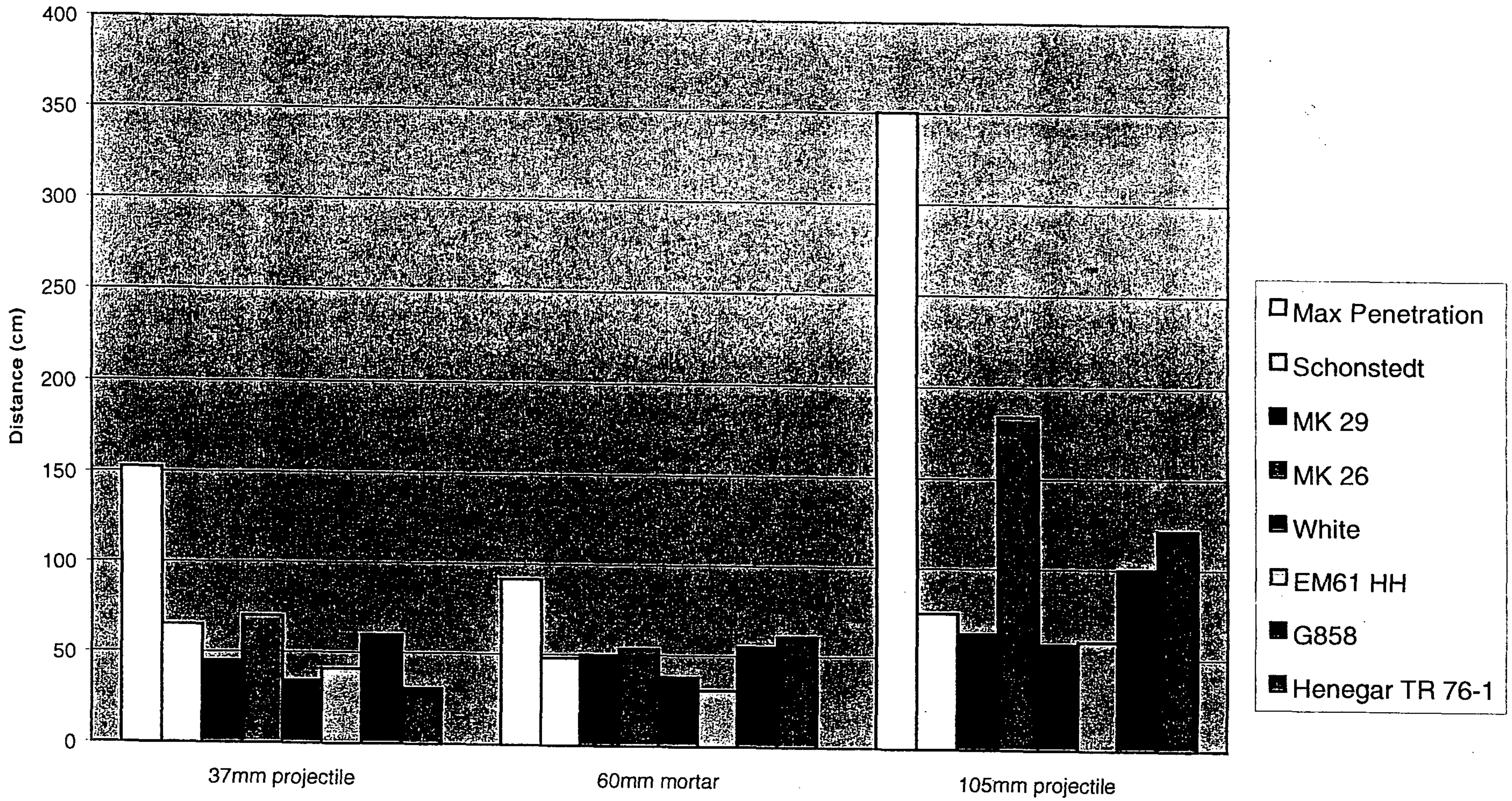

Figure 6-2 Penetration Depth, Maximum Depth Of Reliable Detection, And Maximum Detection Range For Panama Tested Sensors

6.1.4 Conclusions

The above results are due to the relationship of distance to signal strength of the various detectors. As a rule of thumb, gradiometers have a $1/r^4$ response in the far field while the active EM devices have a $1/r^6$ response in the far field (far field being defined as at least twice the sensor separation in gradiometers and twice the coil diameter for active EM's. For example, if one doubles the sensor to target distance, the gradiometer signal will be $1/16^{th}$ while the EM will be $1/64^{th}$). Effects of sources of magnetic noise are not addressed and these maximum detection distances represent a "best case" scenario since there is only an air medium between the sensor and target.

When the measured maximum detection ranges are compared to the maximum probable penetration depths for each of the test targets (Figure 6-2) it is obvious that even under the best conditions the detectors are not technically capable of detecting items down to the maximum penetration depth. Also included in the graph is the maximum reliable detection range for that particular type of target. The maximum reliable detection range offers a threshold for determining if the detector reading is "reliable" and serves only as a comparison to the work done in Panama (Henegar TR-76-1).

From the results of the evaluation, the tested technologies are not currently available to detect 100% of the potential UXO items on the ranges in Panama. The only effective method of clearing an area down to the estimated maximum penetration depth would be to survey and remove layer by layer until the maximum penetration depth is reached.

6.2 Detector Field of View Evaluation

6.2.1 Purpose

Despite the limited range of the detectors to find deeply buried items, the sensors are effective in finding shallow buried targets but only when properly employed. Whenever practical, ordnance detection surveys are usually conducted in grids so that data analysis tools can be brought to bear on the problem. Grids are usually set up to cover a pre-determined area and samples are taken with the sensors at various points within the grid. The gridded area is usually surveyed in a series of parallel survey lanes, which are run consecutively, until the entire area has been covered. Generally, the data is not rectilinear in nature and tends to be "sample rich" in the direction of travel and "sample poor" perpendicular to the direction of travel. The terms "sensor swath width" or "sensor spacing" are used to define the distance between parallel lanes of travel and often contain 20% or even 10% of the samples that exist along the line of travel. If, for example, a sensor samples at 10 hertz and the distance covered in one second is one meter and constant velocity is assumed, a reading is collected every 10 cm at regularly spaced intervals. If the swath width is one meter, the perpendicular sample space is 100 cm or 10 times as far. For accurate surveys, and in order to minimize the number of targets potentially missed during the survey, the minimum swath width or sample spacing must be calculated. This evaluation is also referred to as the spatial detection in the horizontal plane. The purpose of this evaluation is to determine the sensor field of view or how far in the horizontal plane can the sensor be and still detect the item.

6.2.2 Procedure

A test grid was constructed on Empire Range measuring 2 meters by 2 meters with the center of the grid at location (0,0) in Cartesian coordinates. The area was swept clean of any sources of magnetic or conductive material (noise) that could influence the evaluation. The area was then gridded with string denoting .25, .50, 1, and 2 meter spacing in the X, Y field. The test targets were placed in the center of the grid (0,0) on the ground with longitudinal axes facing north. The detector was then placed at each node and readings were taken at heights above the target at .25, .50 .75 and 1 meter increments. Taking readings at the various positions allowed for a 3-dimensional view of the item with respect to the sensor (how the sensor was affected by the target with respect to their relative orientations). This procedure was repeated for each target and sensor used (see Appendix A for Target descriptions). Two detectors were evaluated (the Mk 29 and the Mk 26) because they were the best representatives of their respective technologies (gradiometer and electromagnetic induction) according to the maximum detection range detection tests. Figure 6-3 shows a 37mm projectile test article placed in the test grid.

6.2.3 Results

The values taken at each 3-dimensional node were plotted in a magnitude map for each sensor and each target configuration. Figures B-1 through B-4 (see Appendix B) are for the MK 26 detector and Figures B-5 through B-8 correspond to the MK 29 data. The magnitude maps have a legend on the right that shows the variation of the magnetic field intensity. Each magnitude map shows the gradient magnetic field distribution at the specified constant height. The interpretations of the MK 26 and Mk29 magnitude maps are included below.

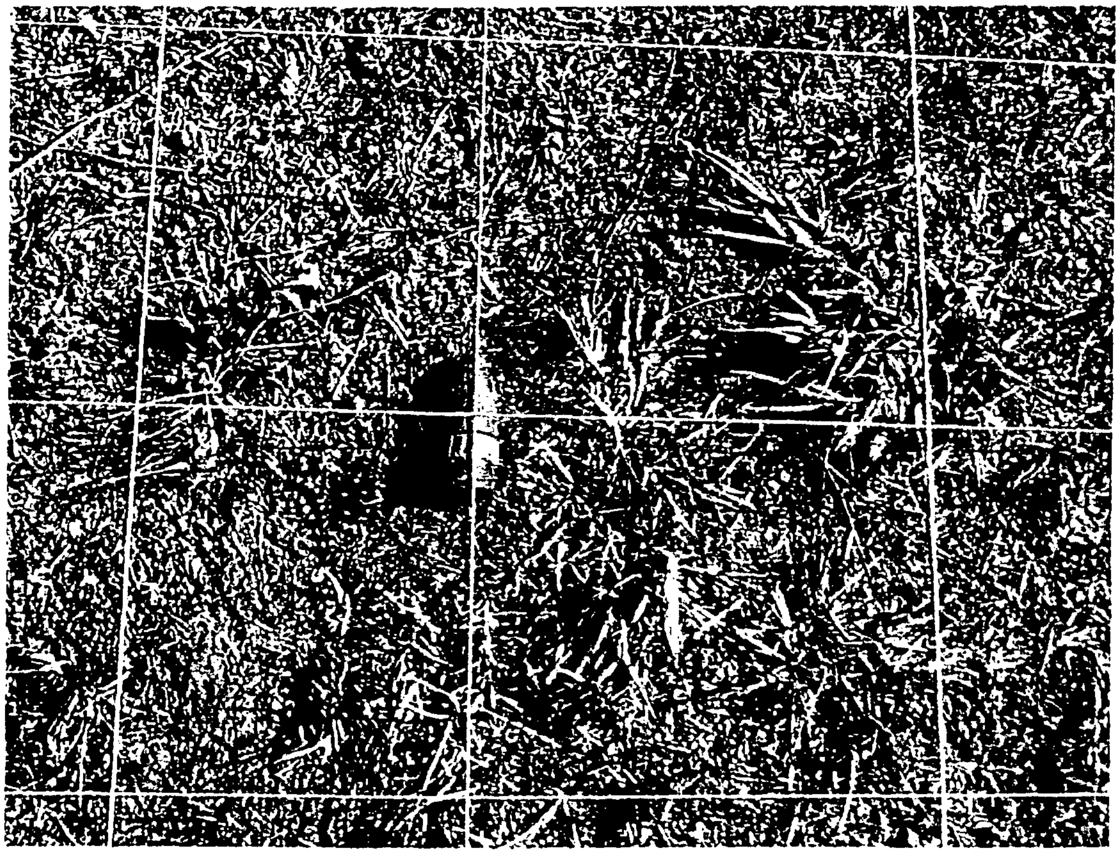

Figure 6-3 37mm Projectile In Test Grid

Interpretation of Mk 26 Magnitude Maps

The signal strength at each given node (x, y and z) is represented by colors on the magnetitude map. Green represents the median value of the graph while blue represents a lower value and red represents a higher value. One task of post processing is to subtract the "dc bias" component of the data so that the green area fluctuates around 0 while values on the red side are positive and the values on the blue side are negative. This technique is also called normalization. The dynamic range of these values is the absolute value of the difference between the high and low readings. As a rule of thumb for threshold detection, a valid anomaly is determined by multiplying the ambient noise floor readings (the area in green) by a factor of four. As an example, if the green area represents fluctuations of +/- 5 nT after post processing it would be indicative of the ambient magnetic field in the absence of buried targets. Multiplying by four would mean that an anomalous detection would only be logged for readings that were at least plus or minus 20 nT or greater. In other words if the detector's response from the target was less then 20 nT the target would not be considered detected. Note also the "dipole" nature of some of the gradiometer graphs. After normalization, the graphs show that positive increases in magnetic field readings are closely associated with negative increases in magnetic field readings (dipoles).

Interpretation of Mk 29 Magnitude Maps

For the Mk 29, each picture represents a constant sensor height above the ordnance item with red showing a valid signal and green showing the absence of any signal (colors other than red or green are indicative of the graphics program interpolating between discrete data points to show a smooth transition). Since, the MK 29 instrument only provides an audio response the plot was created from a series of binary decisions (i.e. was it detectable at each node yes/no).

6.2.4 Conclusions

The magnitude maps relate position, in meters, along the x, y axis and the strength and/or type of signal as a color. The maps reflect that the optimal spacing width is .5 meters for both the Mk26 and Mk 29 detectors. Although spatial distribution testing is an important metric for sensors and their operators, operating detectors in an environment like Panama may not be conducive to survey areas where well-defined lanes can not be established and maintained. For example, during the SI transect surveys the detectors had to be used in a "mag and flag" mode because of the difficulties experienced with the terrain and navigation. The rough terrain made it very difficult to maintain straight well-defined swaths at an even pace which is required to link the sensor data with a position on the earth (GPS was not an option because of the jungle canopy). A further analysis of terrain and the difficulties associated with implementing UXO detection technologies is explored in Section 8 of this report.

7.0 DETAILED ANALYSIS OF SI DATA

To gain more information on the performance of the sensors in the Panamanian environment a detailed analysis of the SI data collected at the calibration reference area is presented in this section of the report. The purpose, procedure, results and conclusions of the analysis are provided below.

7.1 Calibration Reference Area

A reference area is an area designated for evaluating ordnance detectors in a controlled condition in an environment where the detectors will be used. An area of the range that has not been used in the past for ordnance testing and does not contain UXO or ordnance related debris was selected and known targets similar to the ones expected to be found on the actual survey areas were buried there. The various sensors were then used to survey the area to see if the controlled targets could be found.

7.1.1 Purpose

The purpose of a reference area is to assess the subsurface detectors operating performance on a known area prior to implementing the technology in the field. This assures that the technologies do indeed work in the intended environment and provides a gauge for the capabilities and limitations of the detectors in the target environment. Many environmental factors effect the performance of the sensor including background noise associated with the local environment. Some instruments offer sensor settings that can be used to compensate for background noise levels. Therefore, the reference area also serves as an area where subsurface detection equipment can be fine-tuned to the local environmental conditions allowing the instruments to perform at a setting optimal for that local environment.

Thirty-three targets similar to the types expected to be on the ranges in Panama were buried in a north-south orientation at various depths and angles of inclination. The targets buried at the calibration reference area are listed in Table 7-1. The response of a detector is a function of the parameters of the target itself including type, size, mass, depth, orientation and altitude of the target in a given environment therefore, a variety of target scenarios were created. The maximum depth any target was buried to was two meters. Targets were not buried to their respected maximum penetration depths, as presented in Section 2, because the sensors were not capable of locating targets to the maximum penetration depths for most targets (see Section 6.1).

Table 7-1 Ordnance Emplacement Summary For Calibration Reference Area

Target No.	Key No.	Description	Depth (meters)	Azimuth (")	Declination (*)	Weight (lbs.)
1	B-1	GP 250-lb bomb	1.8	North	Flat	114.0
2	B-2	155-mm projectile	2.0	North	Flat	96.0
3	B-3	GP 100-lb bomb	0.8	North	Nose Down 45E	41.75
4	B-4	155-mm projectile	1.2	North	Nose Up 45E	52.5
5	B-5	155-mm projectile	1.5	North	Nose Down 45E	54.5
6	B-6	60-mm mortar	1.5	North	Nose Down 45E	3.8
7	B-7	81-mm mortar	1.0	North	Flat	10.25
8	B-8	60-mm mortar	1.0	North	Flat	3.8
9	B-9	81-mm mortar	2.0	North	Flat	10.5
10	B-10	60-mm mortar	0.5	North	Flat	3.8
11	B-11	82-mm mortar	1.3	North	Nose Down 45E	5.75
12	B-12	60-mm mortar	1.0	North	Flat	3.75
13	B-13	BDU 33	1.2	North	Flat	23.25
14	B-14	82-mm mortar	0.5	North	Nose Up 45E	5.75
15	B-15	82-mm mortar	2.0	North	Flat	5.5
16	B-16	82-mm mortar	1.0	North	Nose Up 45E	5.5
17	B-17	60-mm mortar	0.5	North	Nose Up 45E	3.8
18	B-18	60-mm mortar	0.25	North	Flat	3.8
19	B-19	Mk-19 practice bomb	1.0	North	Nose Up 45E	12.75
20	B-20	60-mm mortar	0.25	North	Nose Down 45E	3.8
21	B-21	82-mm mortar	0.8	North	Flat	5.75
22	B-22	60-mm mortar	1.2	North	Flat	3.75
23	B-23	81m mortar	1.5	North	Nose Up 45E	10.25
24	B-24	40-mm grenade	0.1	North	Flat	0.5
25	B-25	40-mm grenade	0.05	North	Flat	0.25
26	B-26	40-mm grenade	0.06	North	Flat	0.5
27	B-27	40-mm grenade	0.08	North	Flat	0.5
28	B-28	40-mm grenade	0.08	North	Flat	0.5
29	B-29	40-mm grenade	0.06	North	Flat	0.5
30	B-30	40-mm grenade	0.06	North	Flat	0.6
31	B-31	40-mm grenade	0.1	North	Flat	0.75
32	B-32	40-mm grenade	0.06	North	Flat	0.6
33	B-33	40-mm grenade	0.05	North	Flat	0.25

Notes: all weights are empty case weights mm millimeter lbs. Pounds

7.1.2 Procedure

The subsurface survey team was given the boundaries of the reference area and was informed that 33 targets of various sizes and depths were located within the boundaries. They were not given any other data associated with the targets. The team then surveyed the area with each of the following systems the G858 Magnetometer, the EM sensor (EM61) cart mode, and the EM61 HH detector. The procedures used for each detector are included below.

7.1.3 G858 Magnetometer System

The magnetometer data was collected over the reference area using two sensors mounted on a wheeled cart. A base station was also utilized during the survey to measure the diurnal drift or variations in the earth's magnetic field. Quality assurance (QA) procedures including monitoring of the internal diagnostics, battery, and audio output were used during the survey to ensure data integrity. After the survey, the data was then downloaded into the target analysis software for processing.

7.1.4 EM61 Cart Mode

The EM61 standard cart mode was used along survey lanes spaced at 1 meter apart and at .2 meter intervals along the data lines. QA procedures including monitoring of the battery, data logger/controller, and audio output were used during the survey to ensure data integrity. The system was also tested with a metallic test object placed on the surface prior to the actual survey of the reference area. After the survey, the data was then downloaded into the target analysis software for processing.

7.1.5 The EM61 Hand held

The EM61 HH was used along survey lanes spaced at .5 meters apart and at .2 meters intervals along the data lines. The identical QA procedures as the EM61 cart mode were used to ensure data quality and integrity. After the survey, the data was then downloaded into the target analysis software for processing.

7.1.6 Results

The post processed target maps are presented in Appendix C and are labeled as C-1, C-2 and C-3 for the G858, EM61 cart and EM61 HH respectively. Taking the target declarations the P_D and the false alarm ratio (FAR) can be calculated using target analysis procedures similar to the ATD sensor evaluations conducted by USAEC and NAVEODTECHDIV at the JPG. These procedures use a circular area with a 1-meter radius drawn around the center point of each target, which defines the "detection zone" of that particular target. If the selected target declarations fall within the circle of radius 1 meter the target was reported as a true-positive. The 1-meter critical radius (R_{crit}) circular detection areas and the selected anomalies for each sensor are presented in Figure 7-1. The G858 magnetometer target selections are in red. The EM61 standard cart mode target selections are in magenta. The EM61 HH target selections are in green.

The P_D for each sensor is calculated by dividing the number of anomalies correctly selected by the total number of anomalies buried in the reference area.

$$P_D = \text{Probability of detection} = (\text{\# targets detected})/(\text{\# baseline targets surveyed})$$

The calculated P_D for each sensor is presented in Table 7-2.

Table 7-1 Probability Of Detection And False Alarm Ratio (FAR)

Sensor	Reported Targets	Correct Selections	Available Targets	Pd	FAR
G858 Mags	47	16	33	48.5%	1.94
EM61 Cart	50	22	33	69.7%	1.27
EM61 HH	77	23	33	66.7%	2.35
All Sensors Combined	174	31	33	93.9%	4.61

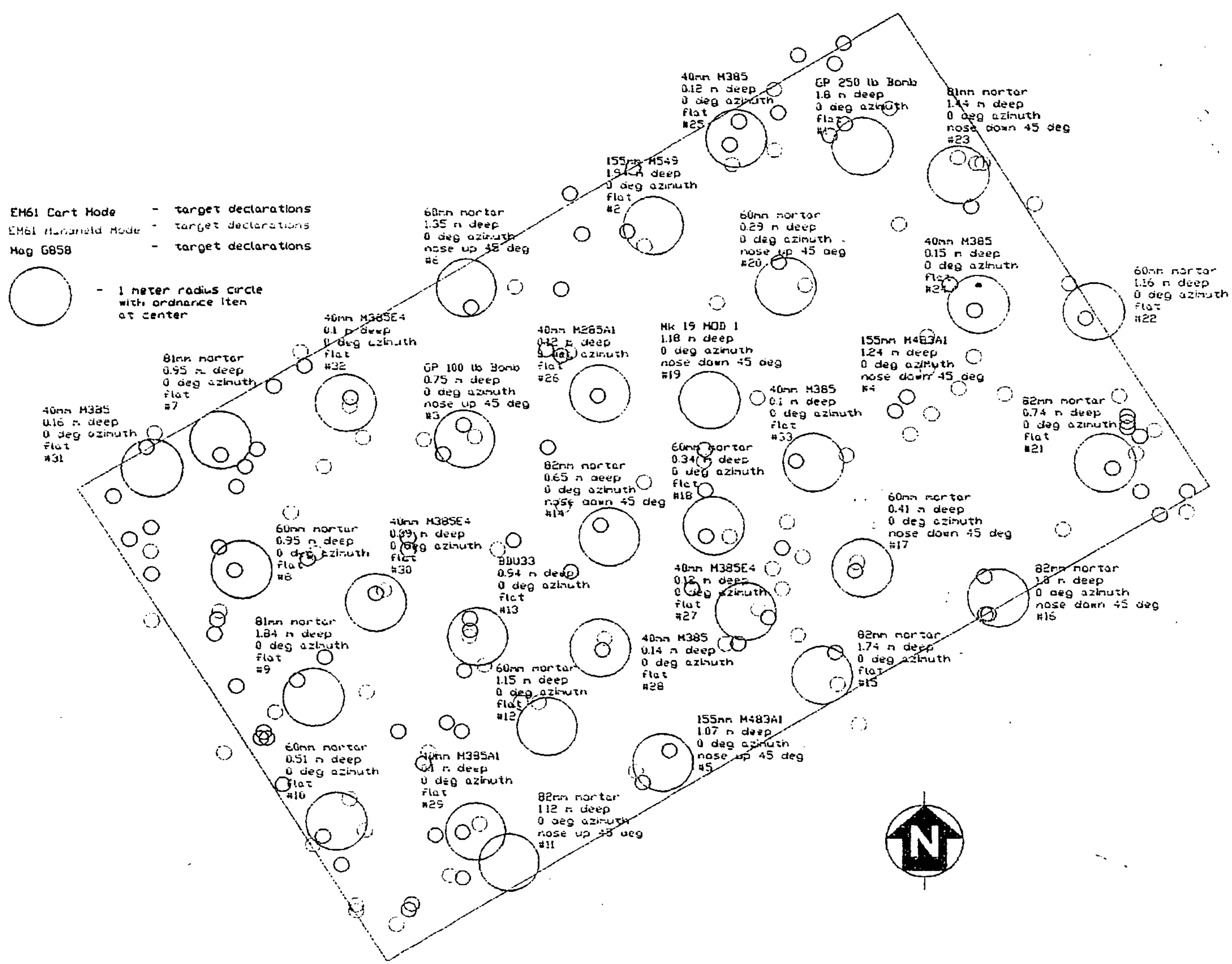

Figure 7-1 Panama Calibration Area

Each sensor reported a substantial number of more selections than available targets or false alarms. False alarms are the target selections that were not made from ordnance items. The G858, EM61 cart and EM61 HH sensors reported a FAR which is the number of false alarms (reported targets minus correct selections) divided by the number of ordnance items detected (correct selections) of 1.94, 1.27, and 2.35 respectively. The FAR compares more favorably in Panama than to JPG Phase II ATD metrics where the average FAR was approximately 13.65 for land based sensor systems (JPG Phase II Report). A further analysis of false alarms is covered in Section 8 of this report.

This procedure for determining P_D opens up the possibility for systems to achieve a high P_D solely by generating a large number of target reports. Therefore, a random probability of detection (P_{random}) was calculated for each system. P_{random} is the expected fraction of baseline ordnance targets that would be detected if the total number of target reports of a system were randomly distributed within the search area, as opposed to being specified by the demonstrator. It is calculated as follows:

$$P_{random} = 1 - e^{-\lambda}$$

where $\lambda = np$

n = number of target reports

R_{crit} = critical radius in meters

p = probability of having a report within R_{crit}

$$p = \frac{\pi \; (R_{crit})^2}{A}$$

A = Area surveyed (m^2)

A P_{random} that is close to or exceeds the calculated P_D is indicative of a detection capability that may be due to chance. P_{random} values were calculated for the Geometrics G858 total field magnetometer, the Geonics EM61 EM system configured in the cart mode, and the Geonics EM61 EMHH induction system in the hand held mode and are presented along with the P_D values for comparison in Table 7-3.

Table 7-3 Probability Of Detection And Random Probability Of Detection

Sensor	P_D	P_{random}
G858 Magnetometers	48.5%	21.6%
EM 61 Cart Configuration	69.7%	22.8%
EM 61 Hand held	66.7%	32.8%

Conclusions

The calculated P_D values for the G858 mags, the EM61 cart configuration and the EM61 HH were all higher than their respected P_{random} values. This assures that the P_{Ds} are valid and not due to chance. The G858 magnetometer had the lowest P_D of the three sensors but the data must be evaluated under the sensors known capabilities. The magnetometer is only capable of detecting ferrous items and several of the targets did not contain any ferrous components (40 mm grenades). Therefore, if the P_D is re-calculated without including the non-ferrous targets the P_D rises to 60.9%. Even using the revised P_D values, the EM 61 configured in the cart mode had the highest P_D although the values from the other systems were very close (within 9%). Although P_D is a critical parameter in the selection of a UXO detector other, factors must be considered including navigation concerns, false alarms, and site accessibility which are covered in Section 8 of this report.

Combining the data from all three sensors provides an indication of the performance of a multi-sensor approach. Taking all three surveys together the calculated P_D is 94% (only 2 of the buried targets were not found by any of the sensors). This is consistent with JPG results, which showed P_D's of over 90% by four companies (JPG Phase III Report). The calibration area also confirmed a JPG III trend showing that a multiple sensor approach, particularly EM induction and magnetometers or gradiometers, gives the best results. There were certain constraints in the calibration area including: no target was buried deeper than 2 meters; no target was buried near its estimated maximum depth of penetration; no non-ordnance targets placed at the calibration area; and P_D was calculated using a population of inert ordnance items. Changing any of those constraints may change P_D values calculated. For example, if certain ordnance items were buried to their maximum penetration depths they would be undetectable (see Section 6-1) and therefore, the P_D would decrease.

8.0 UXO DETECTION TECHNOLOGY FINDINGS AND RESULTS

Based upon the SI and EE activities conducted on the ranges in Panama there are issues related to the potential implementation of UXO detection technologies in Panama, which should be considered prior to implementing technologies in the field. The issues concerning implementation include navigation concerns, method of employment (platform), false alarms, and site accessibility. For each issue the purpose or relevance is presented along with the findings and results concerning the issue.

8.1 Navigation Issue

Navigation is a key component when conducting a subsurface survey for UXO. The sensor data must be related to a position on the earth in order for proper target interrogation. The further the data is away from the actual location, the more difficult it becomes to interrogate the target. There are several methods of acquiring and maintaining position information including GPS, and tick wheels (odometers). These methods were evaluated in Panama during the SI and EE efforts and the results of each are presented below.

GPS systems use satellite signals to triangulate the position of the receiver on the earth. Common commercial units are accurate to 10-30 meters depending upon the model. Accuracy is improved when differential GPS (DGPS) configurations are used. DGPS units correct for the inaccuracies inherent in the GPS satellite signals. Accuracy can be increased to sub-meter distances with DGPS units; however, vegetation and overhead cover easily block GPS satellite signals. Dense jungle canopies severely limit the ability of a GPS to acquire satellite signals, therefore, in Panama, GPS units were only effective in open areas. Tick wheels are essentially mechanical odometers that measure distance traveled. With distance data it is relatively easy to relate the sensor data with a position on the earth assuming the operator moves at a constant rate. For example, if 100 readings were taken over a 10-meter straight path at a constant rate then 10 readings were taken per meter or 1 reading every .10 meters. Since the rough and steep terrain limited the operators ability to maintain a constant speed during the transect survey, the tickwheel method proved ineffective.

Since GPS and odometers were ineffective in rough terrain and dense jungle in Panama, the “mag and flag”, or “treasure hunt” approach had to be used. This method requires the operator to review the data in real time and mark the targets as the survey progresses. The area is either marked with flags and/or paint for later interrogation. Figure 8-1 shows an anomaly that was marked in the field during the SI transect surveys.

Figure 8-1 An Anomaly Which Has Been Marked In The Field During The "Mag And Flag" Operation

8.2 Method of Employment (Platform)

From the initial technology evaluation report and from the recent UXO SI effort conducted in Panama it was determined that man-portable UXO detection technologies would be most appropriate for use in Panama. Vehicular platforms could only be used in very limited areas of the ranges while airborne systems would not be effective at all in the Panamanian environment due to the jungle canopy. Therefore the transects were surveyed with the man portable EM61 using the cart and hand held configuration. However, it was quickly discovered that the terrain was not conducive for the cart configuration. In some places the cart had to be pulled up the terrain with a rope which proved to be too difficult. The difficulties associated with implementing UXO detection technologies in various terrain scenarios is discussed further in Section 8-4.

8.3 False Alarm Ratio

Sensors often report more targets than are actually UXO; these "extra" targets are called false alarms. False alarms are the target selections that were not made from ordnance items. The FAR is calculated by dividing the total number of total incorrect targets reported by the actual number of targets detected in the area. This ratio becomes important when implementing UXO detection and interrogation technologies in an area. False alarms represent holes that have to be dug where the targets are either not existent or are non-UXO targets. Detector discrimination is the ability of a detector to characterize a UXO target from a non-UXO target. Although many research and development efforts are underway to increase the target discrimination capabilities of UXO detectors, progress has been slow and no solution exists that is 100% reliable.

Calibration Reference Area

Examining the FARs from the calibration reference area analysis of Section 7, the G858, EM61 cart and EM61 HH had FAR of 1.94, 1.27, and 2.35 respectively. For the G858 almost twice as many false alarms would have to be interrogated for every ordnance item recovered. The EM 61 cart would have 1.27 times as many false alarms while the EM 61 HH would have 2.35 times as many.

Calculating the same statistics for all sensors combined (from Table 7-2) in the multi-sensor approach yields a P_D of 94% but a false alarm rate of 4.61 (almost 5 false alarms would be dug for every ordnance item recovered). Some false alarms may be spatially close to each other and would not count towards the aggregate amount because of the size of the interrogation dig.

Assuming that a PD of 94% is required for cleanup and that our calibration area is indicative of an impact range (one ordnance item every 18 m^2 and no clutter), what level of effort would be required in the cleanup phase? Essentially 143 false alarms for every 608 m^2 (6% of a hectare). That translates to approximately 2350 false digs per hectare. However on the ranges many non-ordnance targets or clutter exists which may not appear as targets to the sensor thus increasing the number of false alarms.

Transect Data

Examining the transect data (see Appendix D) also provides information on false alarm rates. A total of 107 subsurface targets were located and interrogated during the transect surveys on the Empire (.93 hectares), Balboa West (.78 hectares) and Piña Ranges (.89 hectares). The targets were then organized into five categories including: UXO, ordnance-related scrap, non-ordnance-related scrap, magnetic rock, and empty (no target) (see Table 8-1). Discrimination techniques were not used on the transect data because of the "mag and flag" approach used to collect data. The spatial extent and amplitude of the anomalous signal was recorded and were the only metrics used. The table below clearly shows the problem associated with UXO detection; an inability to accurately discriminate UXO from non-UXO, adding tremendous burden to the clean up effort.

Table 8-1 Transect Interrogation Results

TARGET CATEGORY	QUANTITY
UXO	1
Ordnance Related Scrap	52
Non-Ordnance Related Scrap	17
Magnetic Rock	35
No Target (Empty Hole)	2

Calculating the FAR using the method above, the ratio would be 107. This means that for every 107 non-UXO targets (anomalies) dug, only one will be an actual UXO. Although, one must consider that the transects were conducted in areas where the probability of encountering UXO was very low (suspect and very low UXO concentration areas), the FAR would most likely be less in the UXO areas of concern or on actual impact ranges.

Calculation of P_D from Table 8-1 would require a different definition than that used at JPG since ground-truth (targets that have been emplaced in the ground) is known and UXO at JPG are defined as inert ordnance emplaced. If one defines P_D, in Panama, in terms of detector capability then P_D could be defined as "the probability of a valid signal return" which would be 98% [(1+52+17+35)/107]. P_D could also be defined as "the probability of detection of ordnance and ordnance scrap" which would be 50% [(1+52)/107]. Our perspective is that P_D should be defined as "the probability of detection of a UXO item" which would be .9% [1/107].

8.4 Site Accessibility

In order to implement UXO detection technologies in a UXO concentration area, by definition the site must be accessible and traversable. There are several factors, which effect site accessibility and the ability to traverse an area including vegetation and terrain. The greater the vegetation and the steeper the terrain the more difficult it becomes to access and traverse the area. In addition, standard EOD or UXO removal procedures, as discussed in Section 4 of this report, require overgrowth and vegetation to be cleared before personnel can safely enter due to concerns with unplanned encounters with UXO items. The level of effort required to implement technologies in an environment, therefore, is dependant upon the amount of overgrowth removal required and the local terrain.

Overgrowth removal is a difficult and time-consuming task. It is very conceivable that the site preparation phase of the UXO process could take much longer than the actual survey phase because of the amount of overgrowth and vegetation that must be removed. As the density of overgrowth and vegetation increases the level of effort required to clear the site so the ground is visible and traversable increases exponentially. The ranges in Panama are located in a jungle environment, which possess even greater vegetation and overgrowth removal challenges. The Vietnam Grass (*Saccharum spontaneum*) and the Guinea grass (*Panicum maximum*) can grow up to 2 meters in height and often grow in thick groves. The grass can be burned off but a thick stalk is usually left which must be removed or cut down. The semideciduous forests feature thick vegetative canopies ranging from 15 to 50 meters in height. Clearing these areas would require heavy-duty power tools and equipment that may be extremely hazardous to use due to the potential explosive hazards that exist while operating these types of equipment around UXO. Certain UXO can detonate because of excessive vibrations and do not necessarily need to be touched or encountered.

Assuming that the site is cleared and surface swept, the area is ready for a subsurface survey with UXO detection technologies. Current man-portable detection technologies like the ones presented in Section 5 of this report require the operator to carry the sensor and associated equipment over the area of concern. Navigating through a range or impact area with the UXO detection equipment is demanding and exhaustive work even in areas where the terrain is flat and level (0-5% grade). As the slope increases, the ability to negotiate the area and stay on course with the survey pattern decreases to the point where the operator has to focus more on stability and balance than the survey itself (>25% grade). The sensors usually need to be positioned at a constant height above the ground with relatively low amounts of lateral motion. The detectors are highly sensitive where excessive swinging or sensor movement can skew the data. Keeping the sensor in the constant proper orientation is very challenging and gets tougher as the terrain gets worse. The challenge increases dramatically with an increasing grade. In addition the heat and humidity in the tropic environment make the challenging task even tougher.

As noted above, the level of effort associated with implementing technologies varies with the terrain and vegetation of the area of concern. Table 8-2 presents the relative level of effort required to implement man-portable UXO detection and interrogation technologies in various vegetation/overgrowth and terrain scenarios. Four categories were used to describe the qualitative level of effort associated with implementing man-portable UXO detection technologies and manual interrogation methodologies in Panama. The four categories included tractable, rigorous, very difficult, and unrealistic which are defined later in this section. Vehicular and robotic UXO detection and interrogation platforms are not covered in the table because these platforms are only applicable in flat/level (0-5% grade) or gentle sloping (6-15% grade) areas where the vegetation is minimal. Some of the sensors evaluated will work in, swampy, shallow water or wetland areas however, these areas are not specifically covered in the table because they are usually avoided during UXO clearance operations. These areas are avoided because they are considered environmentally sensitive and are inherently dangerous to clear because of the possibility of un-planned UXO encounters.

Table 8-2 Level Of Effort Required To Implement Man Portable UXO Detection And Interrogation Technologies

	Flat / Level (0-5%)	**Gentle Slope (6-15%)**	**Moderate Slope (16-25%)**	**Steep Slope (26-50%)**	**Cliff / Deep Gulch >50%**
Grassland / Pasture/ Exposed Soils	Tractable	Tractable	Rigorous 3	Very Difficult 5	Unrealistic
Tall Dense Grasses	Tractable 1	Tractable 1	Rigorous 3	Very Difficult 5	Unrealistic
Shrublands / Low Forests	Rigorous 2	Rigorous 2	Very Difficult 4	Very Difficult 5	Unrealistic
Dense Overgrowth / Tall Forests	Unrealistic	Unrealistic	Unrealistic	Unrealistic	Unrealistic

The 4 levels of effort are defined as follows:

Tractable: Manageable and controllable using standard commercially available and existing tools, equipment and procedures. The areas which are tractable are the grassland / pasture /exposed soils areas which have a flat/level or gentle grade. (1) The tall dense grasses would first have to be removed. As noted earlier, the grass can be burned off but a thick stalk is usually left which then must be removed or cut down. An example of a flat area that has been burned off and is tractable is shown in Figure 8-2.

Figure 8-2 Flat Tractable Area That Has Burned

Rigorous: Manageable and controllable using standard commercially available tools, equipment, and procedures but requires additional manpower and efforts that may be fatiguing and exhaustive. Areas that would require a rigorous level of effort to implement technologies are the shrubland / low forested areas with flat / level or gentle slopes. (2) As noted earlier the vegetation would have to be removed which would make the task rigorous. Grassland / pasture / exposed soil / tall dense grass areas with a moderate sloping terrain would also require a rigorous effort to implement. (3) Hand held configurations would be more applicable in the areas of a moderate grade as opposed to wheeled cart configurations. Figure 8-3 shows the EM61 HH that was used during the SI effort and Panama on a moderately sloping terrain where the cart configuration was difficult to move and control and in this case had to be pulled up the slope by a rope.

Figure 8-3 EM61 HH On Moderate Slope That Had To Be Pulled Up By A Rope

Very Difficult: Requires specialized tools and equipment of which some are not available and would require an enormous and very exhaustive effort to implement. The areas that would be very difficult to implement technologies include shrublands / low forested medium statured semi-deciduous areas with a moderate slope. (4) As mentioned before, the vegetation would have to be removed which would be very difficult on the moderate slope. The man-portable cart modes would work; however, the hand held configuration is preferred because of the moderate slope. Implementing technologies on grassland / pasture / exposed soils / tall dense grassy / shrublands / low forested areas with a steep slope would also be very difficult. (5) The steep slope will make the hand held detectors the only configurations capable of being used on these areas.

Unrealistic: Requires extreme methodologies and tools that are not compatible with available UXO detection equipment. Areas that are characterized by very dense overgrowth / tall forests statured semi-deciduous forests independent of terrain or areas with a terrain that is a cliff or steep gulch independent of vegetation are unrealistic for implementing UXO detection and interrogation technologies. Figure 8-4 shows an example of very dense overgrowth that would be unrealistic for implementing any UXO detection and interrogation technologies.

Figure 8-4 Very Dense Vegetation

8.5 UXO Detection Technology Conclusions

In summary, all of the detection technologies evaluated are capable of locating anomalies in the Panamanian environment, however, each has limitations. There is no single sensor that is optimal in all conditions. For example, if the terrain is either flat / level or gentle sloping the EM61 or G858 or similar technologies in the survey grid and data logging mode would be the preferred choice. If the area has moderate or steep terrain, where maneuverability is limited, the EM61 hand held, MK 29, MK26, Schonstedt or similar device, would be the preferred choice. Although environmental conditions are a factor in the selection of specific technologies, the anticipated types of targets must also be considered. For example, if a particular range were used for 40mm grenades a gradiometer (MK 26 or Schonstedt) or magnetometer (G858) would not be effective since there is very little ferrous content in those types of ordnance. Therefore, the technology of choice would be one of the all metals locators (EM61 or Mk29). In addition to terrain and target type, depth is also a factor for technology selection. For example, if the anticipated targets were deep, ferrous items then magnetometers would be the technology category of choice. In summary, no single detector exists that is optimal in all areas of Panama in finding all potential

UXO items therefore, a "tool box" of ordnance sensing technologies is suggested for the Panamanian ranges.

9.0 UXO INTERROGATION PROCESS

After an area has been surveyed with a detector or series of detectors and a target list is generated the next step in the UXO process is to interrogate those targets to determine if they are UXO. Specifically UXO interrogation refers to various UXO clearance activities, including excavating and positively identifying UXO. The disposal process, which involves destroying, rendering safe, or removing the UXO or explosive hazard from the area of concern, is not covered in this report.

Although there are many specific tools, equipment, and procedures used in the UXO interrogation process they can be categorized into one of three methods or modes of operation: manual, mechanized or remote controlled / tele-robotic. The initial technology evaluation report was used as background material for this report. A description of each method of UXO interrogation is presented below along with areas in Panama where the methodologies were utilized and evaluated during the SI and EE efforts.

9.1 Manual Methods

Manual UXO interrogation methods use human energy and are performed entirely without mechanized equipment. Standard manual interrogation methods include using shovels and other digging tools to excavate soil to expose the anomaly, which potentially could be a UXO. Such methods are obviously labor-intensive and the effort involved often increases exponentially as the target depth increases. Additional UXO detection activities are generally required with manual interrogation methods to confirm target removals in order to insure that multiple targets do not exist at any single location.

The majority of the targets investigated during the SI effort were manually interrogated including all of the targets interrogated during the transect process. Typical hand tools including picks and shovels were used in the process. The results of the evaluation of manual interrogation methodologies for use in Panama are presented in Section 10 of this report.

9.2 Mechanized Methods

Mechanized UXO interrogation methods includes the use of systems such as excavators, bulldozers, front-end loaders, and other heavy construction equipment to assist with interrogation efforts. The most common mechanized tools used for UXO interrogation efforts are the backhoe-type excavators. As the interrogation depth increases, the precise location of the buried UXO becomes more difficult to determine, and the interrogation process could become a major excavation effort.

No specific mechanized technologies were used in Panama during the SI or EE. However, evaluation data for a mechanized system is very similar to the results of the robotic systems which are covered in Section 10.2, therefore, they are not specifically covered in this report.

9.3 Remote Controlled – Tele-robotic Methods

Remote-controlled UXO interrogation systems include tele-robotic and autonomous systems. In general, remote-controlled UXO interrogation systems are mechanized systems that can be controlled remotely thus taking the operator outside the area of immediate hazard area.

Remote-controlled systems typically include navigation and positioning systems, a command and control center, and a communications component. The navigation and positioning system tracks and records the vehicles position within the area of concern. Typical navigation systems include a differential GPS technology, which uses satellite signals to pinpoint the location of the robotic vehicle. The command and control center is a station set up outside the immediate operating area where the operator stays. The communications component is the device used in the command and control center to send and receive data to and from the robotic vehicle. Popular technologies include radio frequency (RF) systems.

Robotic technologies utilized in Panama during the recent SI activities was limited to the All-purpose Remote Transport System (ARTS) which is a USAF built platform designed to perform many tasks remotely. The ARTS platform is basically a tele-operated multipurpose platform that is controlled through a command and control station which uses RF based technology for the communications components and DGPS for navigation. The multipurpose platform allows for a variety of tool and hardware configurations to be utilized by having a common interface. During the SI effort the ARTS was used with the grass-cutting configuration. The system was not used to interrogate technologies during the SI, however, the data gathered from the performance of the ARTS in the grass cutting mode is believed to be identical to the performance expected if the system were to be used in the target interrogation configuration. The results of the evaluation of the ARTS platform is covered in Section 10.2 of this report.

10.0 UXO INTERROGATION METHODOLOGIES EVALUATION FINDINGS

UXO interrogation methodologies were evaluated in terms of the system's effectiveness in the Panamanian environment to perform UXO interrogation tasks. Manual and tele-robotic methods were evaluated for this report based from recent UXO SI activities conducted on the ranges in Panama. Mechanized methods are not specifically evaluated, however, the evaluation would be similar to the tele-robotic method evaluation except that the system operator would be in the immediate hazard area.

10.1 Manual UXO Interrogation Method Evaluation

Manual UXO interrogation methods could be implemented with varying degrees of difficulty in nearly all areas of the ranges in Panama, provided the vegetation and overgrowth were removed, except in areas of extreme terrain including steep slopes or deep gulches (>50% grade). Manual UXO interrogation methods are inherently dangerous for the operator especially in areas with steep terrain (>25% grade). The difficulties experienced by the operator while maneuvering around would add risk to an already dangerous task. Manual interrogation is effective, however, as the depth increases the level of effort increases exponentially.

During the SI transect surveys targets were interrogated at Empire, Balboa West and Piña Ranges. It was observed that the targets at Piña required less effort to interrogate due to the soil characteristics of Piña Range versus the Empire and Balboa West Ranges where the soil is much different. Even with the best soil conditions, manual interrogation of deeply buried UXO would be very labor intensive. In addition, manual excavations greater than 1 meter in depth would require shoring or sloping for safety purposes.

Therefore, deep excavations requiring large amounts of soil removal should be done with the use of mechanized or remote-controlled methods. Although accessing the site with hand held tools is logistically easier than entering with mechanized or robotic technologies, manual methods can only be used in accessible areas where well defined safety exits are established and maintained. Areas surrounded by heavy vegetation and rough terrain may not make it possible for proper safety exits to be established.

10.2 Remote Controlled – Tele-robotic UXO Interrogation Method Evaluation

The tele-robotic system evaluated in this report is the ARTS platform that was used in the UXO SI effort in Panama. The ARTS system performed extremely well in certain areas while experiencing major technological difficulties in other areas of the Balboa West and Empire Ranges. In flat / level, open grassland / pasture areas, the ARTS was very effective in rapidly removing vegetation in UXO concentration areas. The system also provided an added measure of safety because the user controlled the system from outside the immediate hazard area. The ARTS had a difficult time negotiating hills and steep terrain. During the SI, the ARTS rolled over several times and required extraction from the site by additional pieces of heavy equipment. Over the SI, the system required several thousand dollars worth of repairs to replace damaged hydraulic and navigation components. The DGPS navigation system on the ARTS was not effective in dense overgrowth areas where the satellite signals were blocked reducing the system accuracy. In addition, the hilly terrain made RF communications difficult because the system required line of sight to effectively transmit commands. Another limitation was the build up of vegetation in the unit air intake, which required operations to stop on a regular basis to allow the machine to cool. Site accessibility is also an issue to consider in deploying robotic vehicles. Robotic vehicles must be able to access the areas of concern. Despite the technical challenges faced in implementing robotic gear the benefit of having the operator outside the area of immediate hazard reduces risk.

11.0 ENVIRONMENTAL IMPACTS / TRADE OFF ANALYSIS

Any UXO clearance operation will have an impact on the environment. These environmental impacts are a function of the technologies implemented the level of disturbance (depth of target interrogation), and the local environment conditions of the area. This report presents a qualitative trade off analysis which examines the short-term and long-term impacts common with the implementation of UXO detection and interrogation technologies. In addition the hazards to EOD and UXO specialist personnel who would implement the technologies are examined along with a discussion of the potential UXO hazard level reductions that might be achieved.

11.1 Environmental Impacts

UXO detection and interrogation activities on the ranges in Panama will have both short and long term environmental impacts including impacts on the soil, vegetation, and wildlife. Short-term impacts are defined as those lasting for the duration of a detection or interrogation project (assumed to be 5 years or less). Long-term impacts are defined as those lasting beyond the duration of a detection or interrogation project and likely persisting more than 20 years.

The degree to which UXO detection and interrogation technologies are implemented will determine the extent of the impacts to the soil, vegetation and wildlife. The impact to the soil is a function of the level or depth to which the soil is disturbed. Using man-portable detection technologies alone would cause small disturbances on the surface of the soil. These surface disturbances would cause short-term impacts such as minor erosion. However, when interrogation technologies are introduced the impacts to the soil increase. Increased surface soil erosion might result in short-term degradation of water quality in nearby streams and tributaries. Some stream bank erosion occurs naturally in forested areas; however, erosion would be accelerated in upland areas once the more resistant surface soil layers were disturbed. Surface soil erosion resulting from vegetation loss is also a potentially significant concern for the ranges in Panama and can result in increased siltation into the canal. Increased siltation in the canal would cause the water level to decrease and this would limit the type and volume of ship traffic through the shipping channel (as it has in the past) or would necessitate dredging the shipping channel more frequently (Miller and Tangley 1991).

The removal of vegetation from the ranges that is required prior to implementing UXO detection and interrogation technologies would impact the environment. If significant range vegetation were to be removed the soil quality would decline severely, resulting in negative long-term impacts. Potential soil quality impacts include rapid decomposition of organic matter and associated depletion of nutrients needed to sustain a rainforest ecosystem, changes in the soil's physical qualities, and rapid erosion resulting from high-intensity rains falling on the unprotected soil surface. Such impacts may lead to irreversible changes in the rainforest ecosystem. Research has shown that average soil loss from primary forest land areas averages 2.4 metric tons per hectare. If the same area were cleared of vegetation and trees (i.e. UXO clearance or logging activities) the average soil loss would increase to approximately 167 metric tons per hectare (a factor of 69 times the amount).

Short-term impacts on vegetation resulting from UXO detection and interrogation would be primarily associated with burning of grassland areas and removal of surface stubble. These grassland areas would be expected to revegetate in one or two years. However, UXO interrogation to significant soil depths would result in destruction of plant root systems, which in turn would lead to long-term adverse environmental impacts.

Long-term impacts on vegetation would occur if forested areas were cleared for large-scale UXO detection and interrogation activities. The long-term impacts of deforestation would include the potential loss of flora species and diversity, endangered species, wildlife habitats and food supplies, and the biological wealth of the rainforest ecosystem. Such impacts would be particularly threatening to already declining tropical ecosystems.

Implementing UXO detection and interrogation technologies in the Panamanian environment will impact the wildlife. Short-term impacts on wildlife would primarily take the form of species displacement during vegetation burning and ground-based activities. Native wildlife species would be expected to return as the grasslands revegetated. Long-term impacts on wildlife resources would include loss of habitats and potential loss of threatened and endangered species. As noted in Section 2 of this report, Empire, Balboa West and Piña Ranges are home to hundreds of plant, mammal and bird species, many of which are globally imperiled, nationally imperiled, or protected by Panamanian law. The environment is so bio-diverse that it is among the best examples of deciduous forests remaining along the Pacific coasts of Mexico and Central America.

The degree and extent of the impacts to the soil, vegetation, and wildlife depend on the particular configuration of technology and extent of UXO interrogation. For example, manual surface clearance would have less severe environmental impacts, while a UXO interrogation to 1 meter below ground surface (bgs) using large automated systems requiring extensive soil excavation could result in significant long-term impacts to the soil, vegetation and wildlife. Before any UXO Detection and Interrogation Technologies are implemented in Panama the short and long-term effects to the environment must be considered. In some cases the impacts may not be acceptable. A general summary of the potential environment impacts is presented in Table 11-1.

ENVIRONMENTAL FACTOR	SHORT TERM IMPACT	LONG TERM IMPACT
Soil	Increase Run-off Increased Erosion	Permanent Destruction of Forest Degradation of Water Quality Increased Siltation Into Nearby Waterways
Vegetation	Temporary Loss of Plant and Floral Species Temporary Loss of Wildlife Food Supplies	Loss of Plant and Floral Species Loss of Biological Resources Increased Siltation Into Nearby Waterways.
Wildlife	Displacement of Wildlife	Loss of Wildlife Species That are Potentially Globally Imperiled, Nationally Imperiled, or Protected Under Panamanian Law.

Table 11-1 Short And Long Term Environmental Impacts Of Implementing UXO Detection And Interrogation Technologies In Panama

11.2 Hazards to EOD or UXO Removal Personnel

Implementing UXO detection technologies or interrogation methodologies in Panama will subject EOD or UXO removal personnel to a hazardous environment. The hazard level for performing UXO detection and interrogation tasks is a function of the types and quantities of ordnance present, the technology or methodology implemented, and the local environmental conditions of the site. Standard EOD or UXO removal procedures require overgrowth and vegetation to be cleared before personnel can safely conduct range clearance activities in an area. However, clearing the overgrowth and vegetation can be an extremely hazardous task and in some cases may be more hazardous then the survey phase itself due to the potential for unplanned encounters with UXO. Using hand held power tools to clear the vegetation would increase the hazard to the operator in some scenarios. Automated tools such as ARTS can be used to clear vegetation and overgrowth with minimal hazard to the user, however, the areas in Panama where technologies such as ARTS can be used are very limited. Even after the vegetation and overgrowth has been cleared, and the ground is visible, the risk from the potential surface and subsurface UXO still exists.

Certain ordnance items, by their design, are more hazardous than others and require special waivers that must be approved before removal actions can be executed on U.S. Army controlled ranges. An example of this would be the waiver that was needed during the UXO SI effort in order to work in the main impact area of the Empire Range where M42 submunitions were found. The M42 submunitions are very sensitive and may detonate under slight movements. In any case the hazard to equipment operators and EOD or UXO removal experts must be considered when deciding on the level of UXO removals. In certain scenarios the level of hazard to personnel and equipment may not be acceptable.

11.3 POTENTIAL UXO HAZARD LEVEL REDUCTIONS

Implementing UXO detection and interrogation technologies will reduce the UXO hazard levels associated with the ranges in Panama, however, they require a large amount of effort to implement and are dangerous to implement. The level of hazard reduction from an area is a function of the amount and types of UXO removed from that area and the confidence level of the removal process the UXO hazard remaining drives the potential land uses for that area. Reduction of the UXO hazard level to the point where an impact area would be suitable for unlimited public use would not be possible due to technology limitations.

12.0 CONCLUSIONS

There are no commercial technologies available today that are capable of detecting 100% of the potentially buried UXO on the ranges in Panama. However, UXO detection technologies are capable of detecting some of the UXO in the accessible areas of the Ranges in Panama Panamanian environment but have limited capabilities and require a large amount of effort to implement. Given the extreme environmental conditions in Panama, man-portable UXO detection technologies used in the "mag and flag" mode of operation are the most appropriate for locating buried UXO. However, the terrain and vegetation are limiting factors in accessing UXO concentration sites. No matter how effective the technology may be, if the site is inaccessible, technology cannot be implemented. In accessible areas of the ranges where technologies potentially can be implemented the vegetation and overgrowth must be removed resulting in both short and long-term impacts to the environment and the Canal watershed. Some of these impacts would be so extreme that they could effect the operation and stability of the Panama Canal. Before any additional UXO detection and interrogation efforts are undertaken on the ranges in Panama, impacts to the environment, hazard to EOD and UXO personnel, and technology limitations should be weighed against the potential benefit from implementing such technologies.

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Appendix A – Targets Used For The Maximum Detection Range And The Detector Field Of View Evaluation

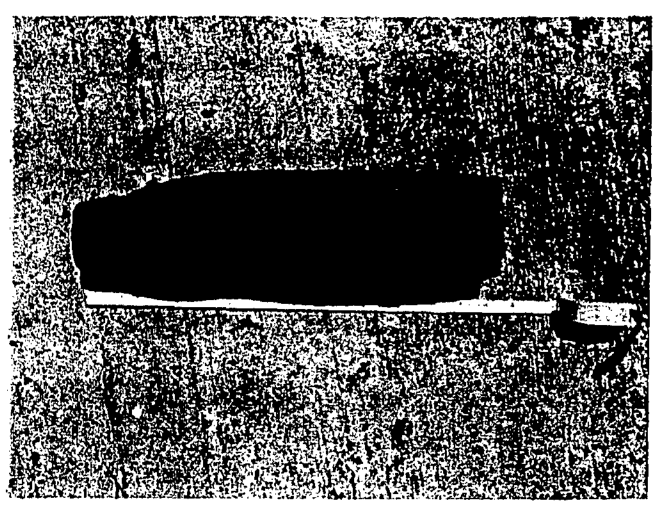
UXO DETECTOR EVALUATIONS

One of the main objectives of the Engineering Evaluation effort was to provide an assessment of UXO detectors in the Panamanian environment. To accomplish this a series of three separate evaluations were conducted with each particular technology. The three evaluations included the maximum detection range evaluation, the sensor field of view evaluation (spatial detection) and the controlled target response evaluation. Each specific evaluation measures a particular characteristic or detector capability. The purpose, procedure, results and conclusions for each of the three specific evaluations are presented in this section of the report. A brief description of the test articles used for the evaluations is also presented.

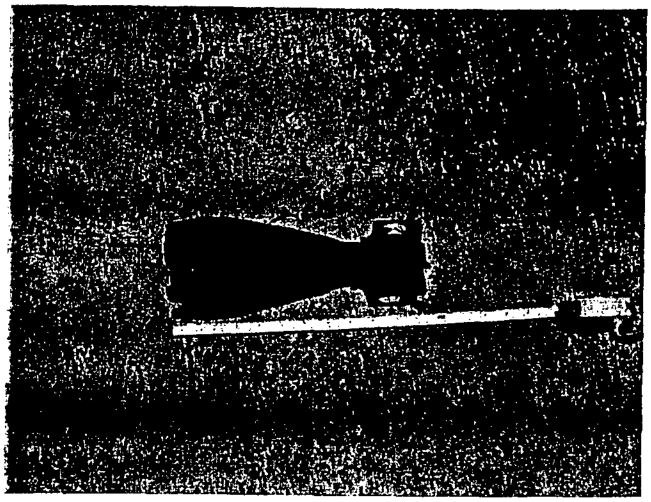
Test Targets

For the sensor evaluations several test articles were used. Four test articles were used for the maximum detection range evaluation and the sensor field of view evaluation and 14 test target articles were used for the controlled target response evaluation.

The four test articles used for the maximum detection range evaluation and the sensor field of view evaluation included inert 37mm, 60mm, 81 mm and 105mm ordnance bodies. The test articles were actually acquired from one of the scrap piles accumulated during the SI conducted on the Empire range. Hundreds of these items were removed during the SI clearance activities and represent the most common items expected to be encountered on the ranges in Panama. A photo and description of each test article is presented below.



TARGET: 105mm Projectile
WEIGHT:
LENGTH: 37 cm
FUZE: None

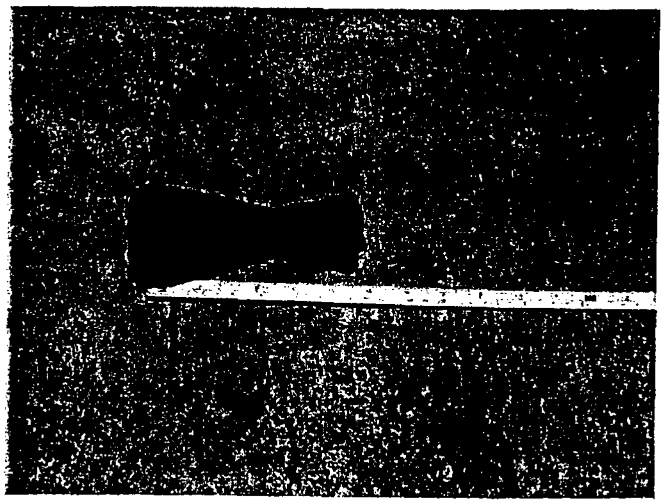


TARGET: 81mm Mortar

WEIGHT:

LENGTH: 28 cm

FUZE: None

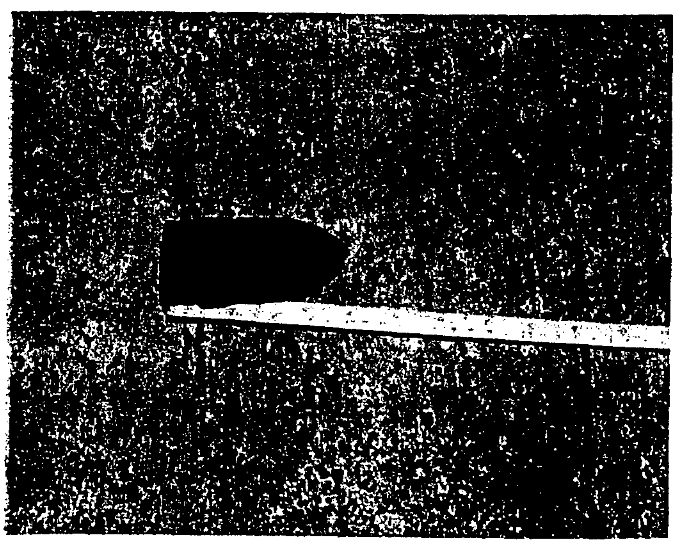


TARGET: 60mm Mortar

WEIGHT:

LENGTH: 14 cm

FUZE: None



TARGET: 37mm Projectile

WEIGHT:

LENGTH: 10 cm

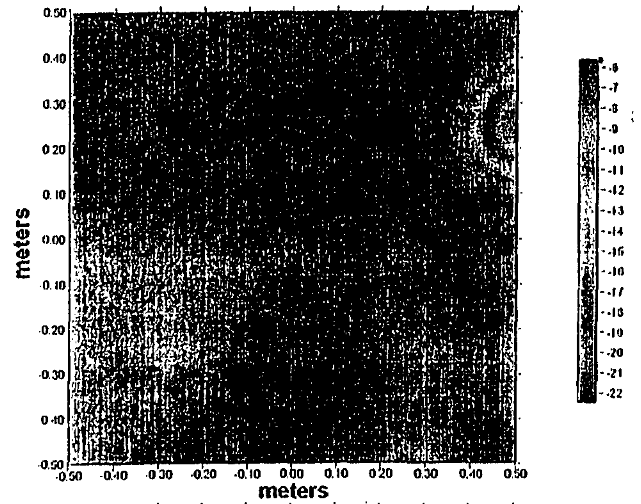
FUZE: None

Appendix B – Magnitude Maps For The MK26 And MK29 Detectors From The Detector Field Of View Evaluation

Target Center of Mass at 0,0

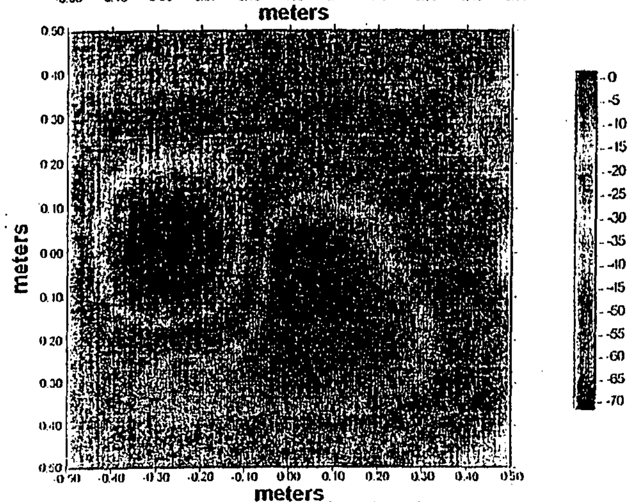
Technology: Gradiometer
Locator: Mk 26
Location: Panama
Sensitivity: 10
Sensor Height (above center of target): 98.15 cm
Target: 37 mm
Target Orientation: (nose) N-S, not inclined
Maximum Detectable Height Over Target: 70 cm
Data Format: x,y,nT

Dynamic Range = 17 nT



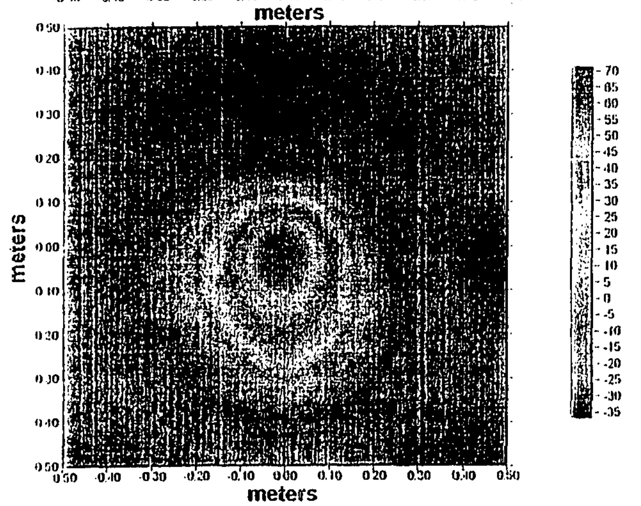
Technology: Gradiometer
Locator: Mk 26
Location: Panama
Sensitivity: 10
Sensor Height (above center of target): 73.15 cm
Target: 37 mm
Target Orientation: (nose) N-S, not inclined
Maximum Detectable Height Over Target: 70 cm
Data Format: x,y,nT

Dynamic Range = 73 nT



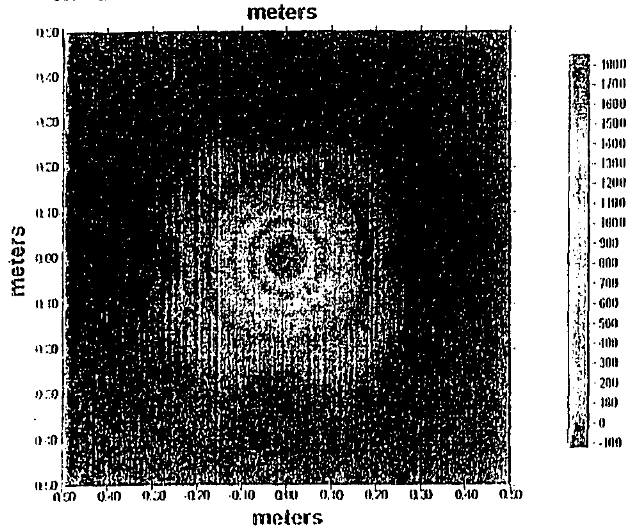
Technology: Gradiometer
Locator: Mk 26
Location: Panama
Sensitivity: 10
Sensor Height (above center of target): 23.15 cm
Target: 37 mm
Target Orientation: (nose) N-S, not inclined
Maximum Detectable Height Over Target: 70 cm
Data Format: x,y,nT

Dynamic Range = 108 nT



Technology: Gradiometer
Locator: Mk 26
Location: Panama
Sensitivity: 10
Sensor Height (above center of target): 6.25 cm
Target: 37 mm
Target Orientation: (nose) N-S, not inclined
Maximum Detectable Height Over Target: 70 cm
Data Format: x,y,nT

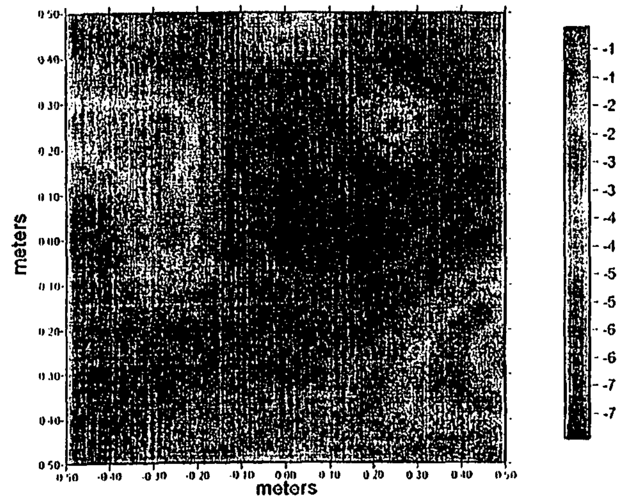
Dynamic Range = 1974 nT



Target Center of Mass at 0,0

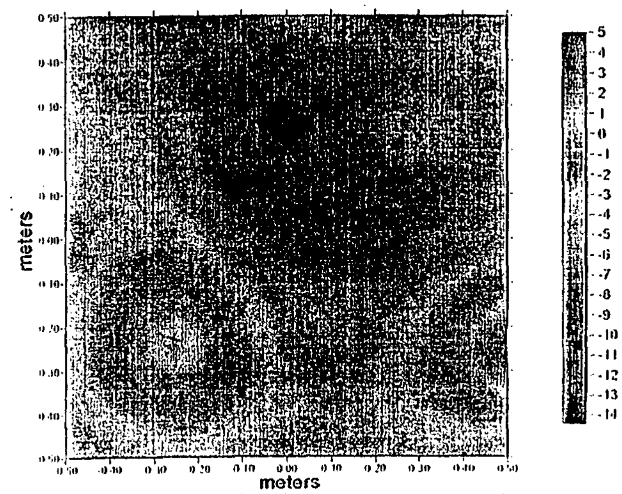
- Technology: Gradiometer
Locator: Mk 26
Location: Panama
Sensitivity: 10
Sensor Height (above center of target): 97 cm
Target: 60 mm mortar
Target Orientation: (nose) N-S, not inclined
Maximum Detectable Height Over Target: 53.5 cm
Data Format: x,y,nT

Dynamic Range = 7 nT



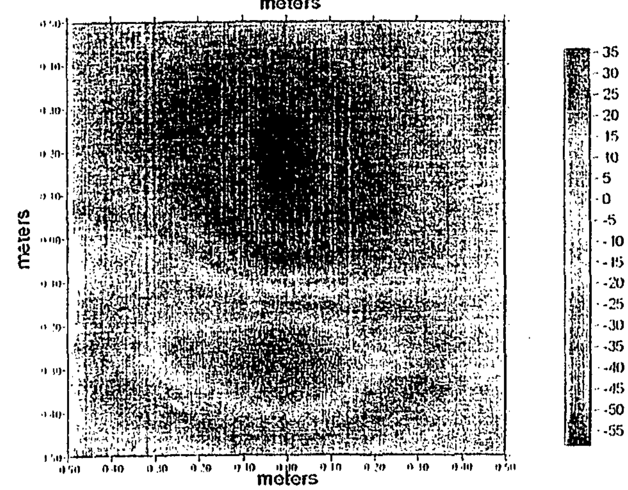
Technology: Gradiometer
Locator: Mk 26
Location: Panama
Sensitivity: 10
Sensor Height (above center of target): 72 cm
Target: 60 mm mortar
Target Orientation: (nose) N-S, not inclined
Maximum Detectable Height Over Target: 53.5 cm
Data Format: x,y,nT

Dynamic Range = 19 nT



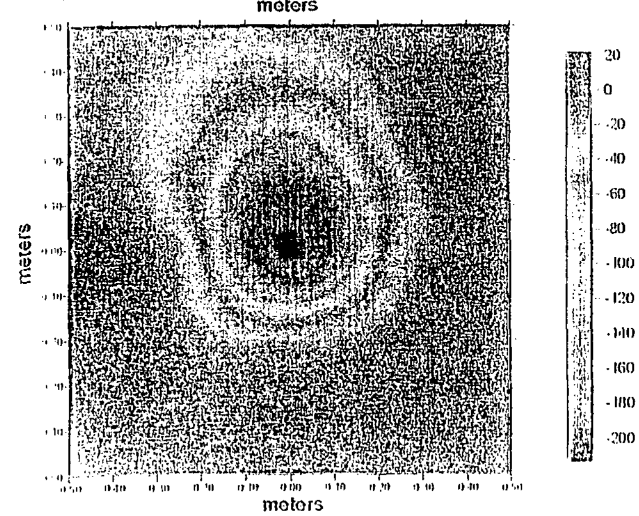
Technology: Gradiometer
Locator: Mk 26
Location: Panama
Sensitivity: 10
Sensor Height (above center of target): 22 cm
Target: 60 mm mortar
Target Orientation: (nose) N-S, not inclined
Maximum Detectable Height Over Target: 53.5 cm
Data Format: x,y,nT

Dynamic Range = 94 nT



Technology: Gradiometer
Locator: Mk 26
Location: Panama
Sensitivity: 10
Sensor Height (above center of target) 5.1 cm
Target: 60 mm mortar
Target Orientation: (nose) N-S, not inclined
Maximum Detectable Height Over Target: 53.5 cm
Data Format: x,y,nT

Dynamic Range = 235 nT



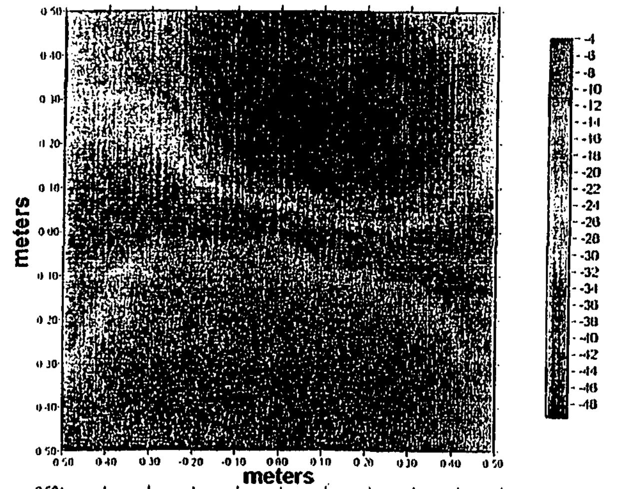
Magnitude Maps of 81mm Mortar

File Name: MK26_81.SRF

Target Center of Mass at 0,0

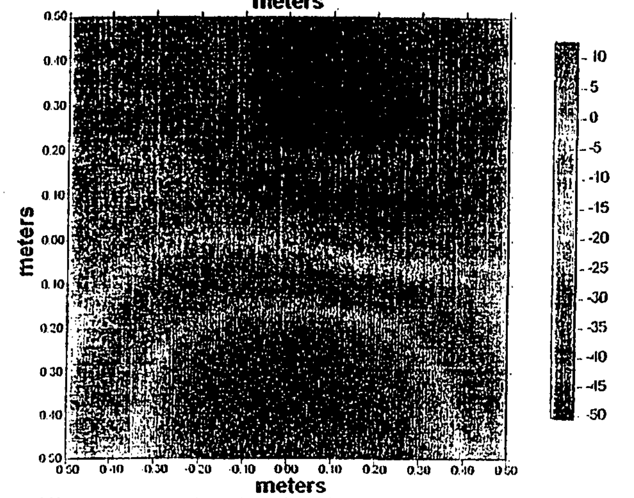
Technology: Gradiometer
Locator: Mk 26
Location: Panama
Sensor Height (above center of target): 95.95 cm
Target: 81 mm mortar
Target Orientation: (nose) N-S, not inclined
Maximum Detectable Height Over Target: 87 cm
Data Format: x,y,nT
Sensitivity: 10

Dynamic Range = 46 nT



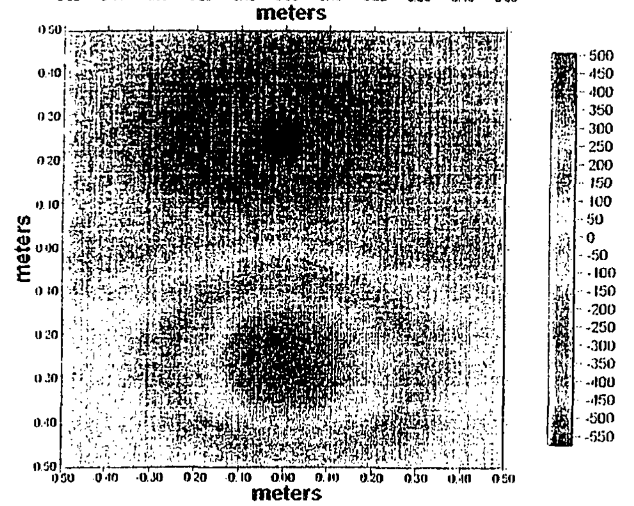
Technology: Gradiometer
Locator: Mk 26
Location: Panama
Sensor Height (above center of target): 70.95 cm
Target: 81 mm mortar
Target Orientation: (nose) N-S, not inclined
Maximum Detectable Height Over Target: 87 cm
Data Format: x,y,nT
Sensitivity: 10

Dynamic Range = 63 nT



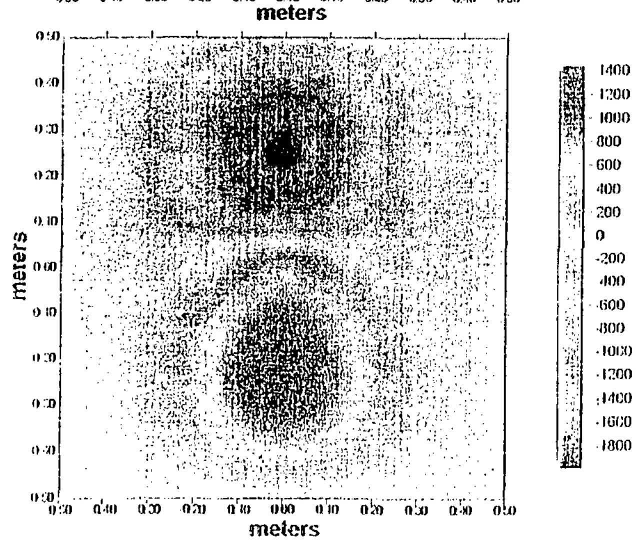
Technology: Gradiometer
Locator: Mk 26
Location: Panama
Sensor Height (above center of target): 20.95 cm
Target: 81 mm mortar
Target Orientation: (nose) N-S, not inclined
Maximum Detectable Height Over Target: 87 cm
Data Format: x,y,nT
Sensitivity: 10

Dynamic Range = 1083 nT



Technology: Gradiometer
Locator: Mk 26
Location: Panama
Sensor Height (above center of target): 4.1 cm
Target: 81 mm mortar
Target Orientation: (nose) N-S, not inclined
Maximum Detectable Height Over Target: 87 cm
Data Format: x,y,nT
Target Center of Mass at: 0,0

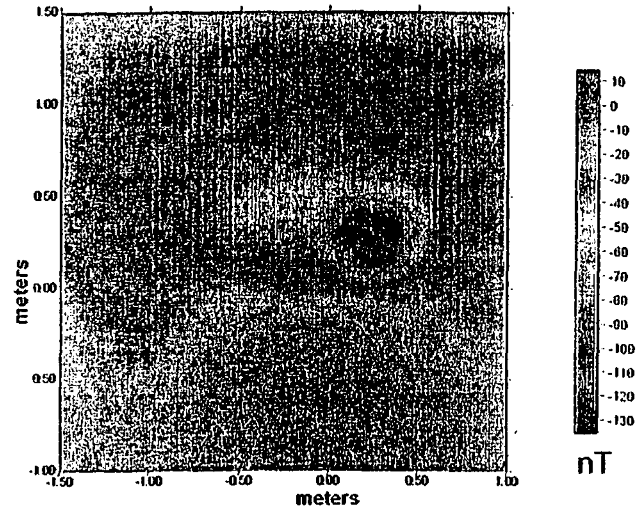
Dynamic Range = 3418 nT



Target Center of Mass at 0,0

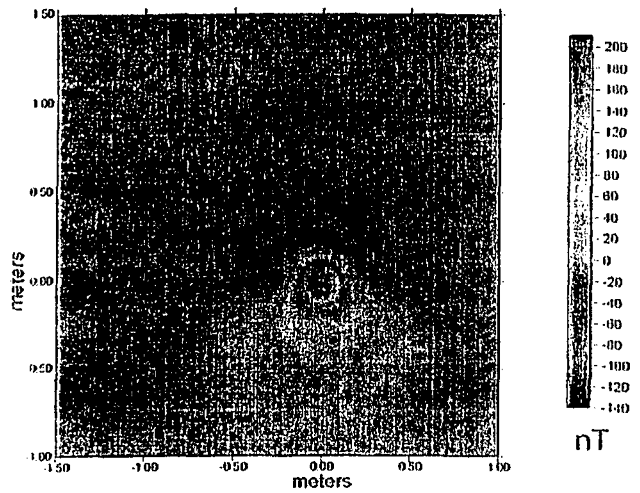
- Technology: Gradiometer
  Locator: Mk 26
  Location: Panama
  Sensitivity: 10
  Sensor Height (above center of target): 94.75 cm
  Target: 105mm projectile
  Target Orientation: (nose) N-S, not inclined
  Maximum Detectable Height Over Target: 184 cm
  Data Format: x,y,nT

Dynamic Range = 150 nT



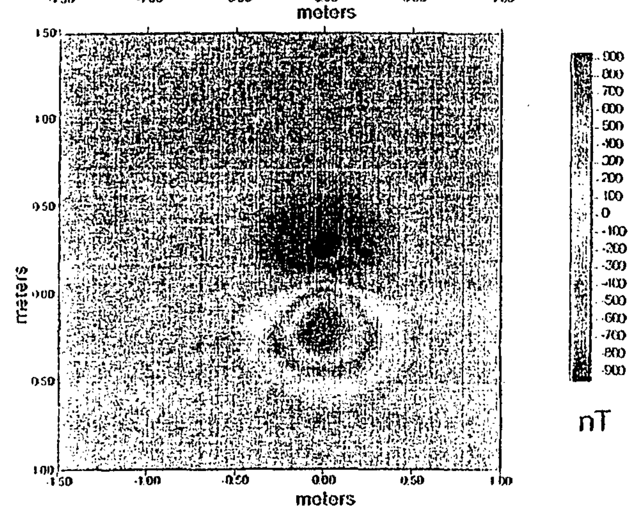
Technology: Gradiometer
Locator: Mk 26
Location: Panama
Sensitivity: 10
Sensor Height (above center of target): 69.75 cm
Target: 105mm projectile
Target Orientation: (nose) N-S, not inclined
Maximum Detectable Height Over Target: 184 cm
Data Format: x,y,nT

Dynamic Range = 351 nT



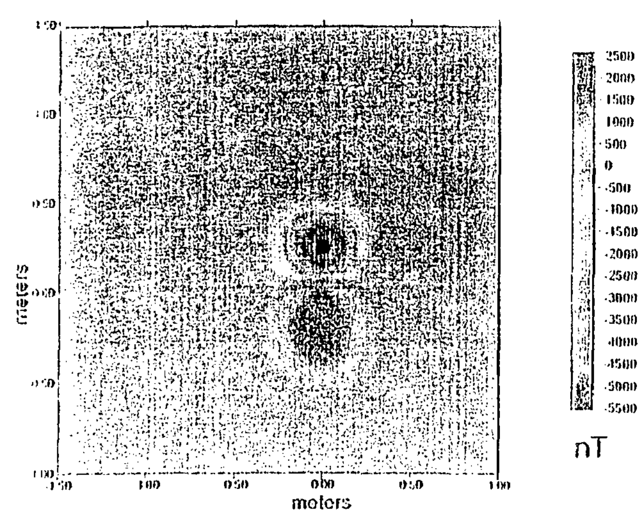
Technology: Gradiometer
Locator: Mk 26
Location: Panama
Sensitivity: 10
Sensor Height (above center of target): 19.75 cm
Target: 105mm projectile
Target Orientation: (nose) N-S, not inclined
Maximum Detectable Height Over Target: 184 cm
Data Format: x y nT

Dynamic Range = 1886 nT



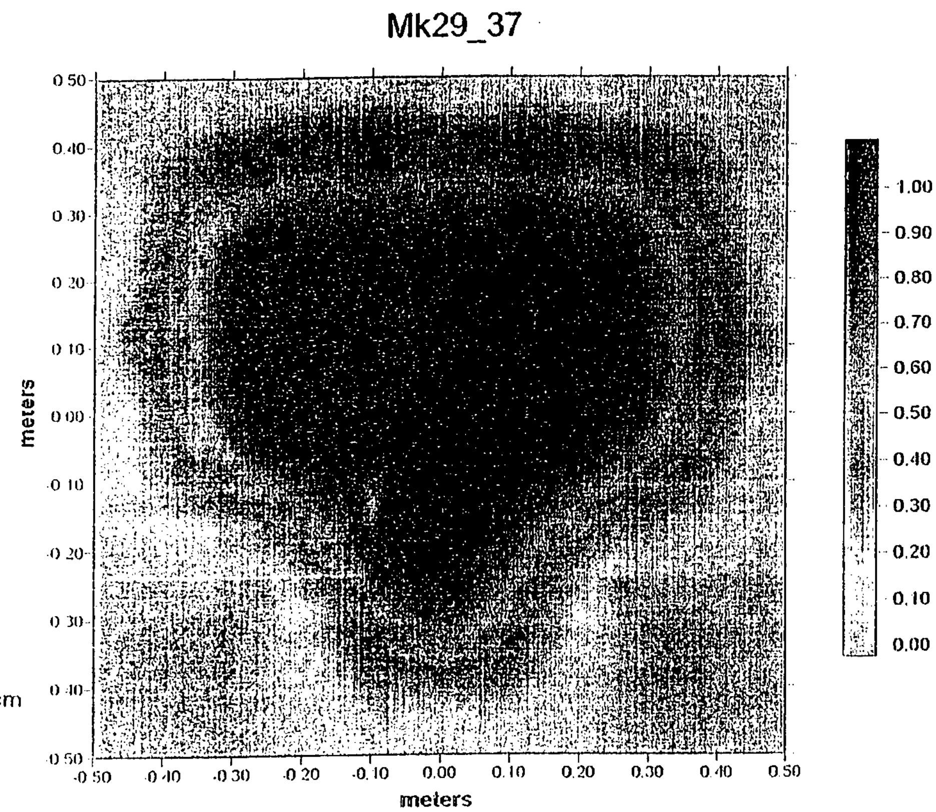
Technology: Gradiometer
Locator: Mk 26
Location: Panama
Sensitivity: 10
Sensor Height (above center of target): 6.25 cm
Target: 105mm projectile
Target Orientation: (nose) N-S, not inclined
Maximum Detectable Height Over Target: 184 cm
Data Format: x,y,nT

Dynamic Range = 8116 nT

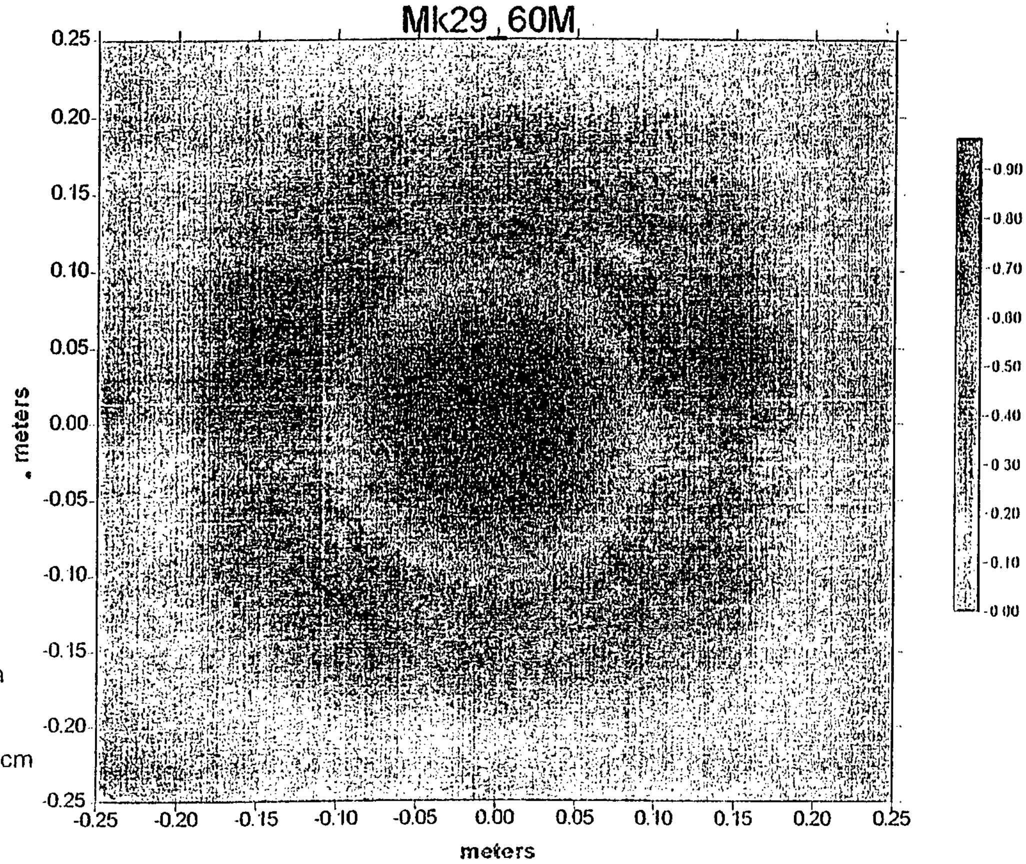


MAGNITUDE MAPS OF 37mm PROJECTILE

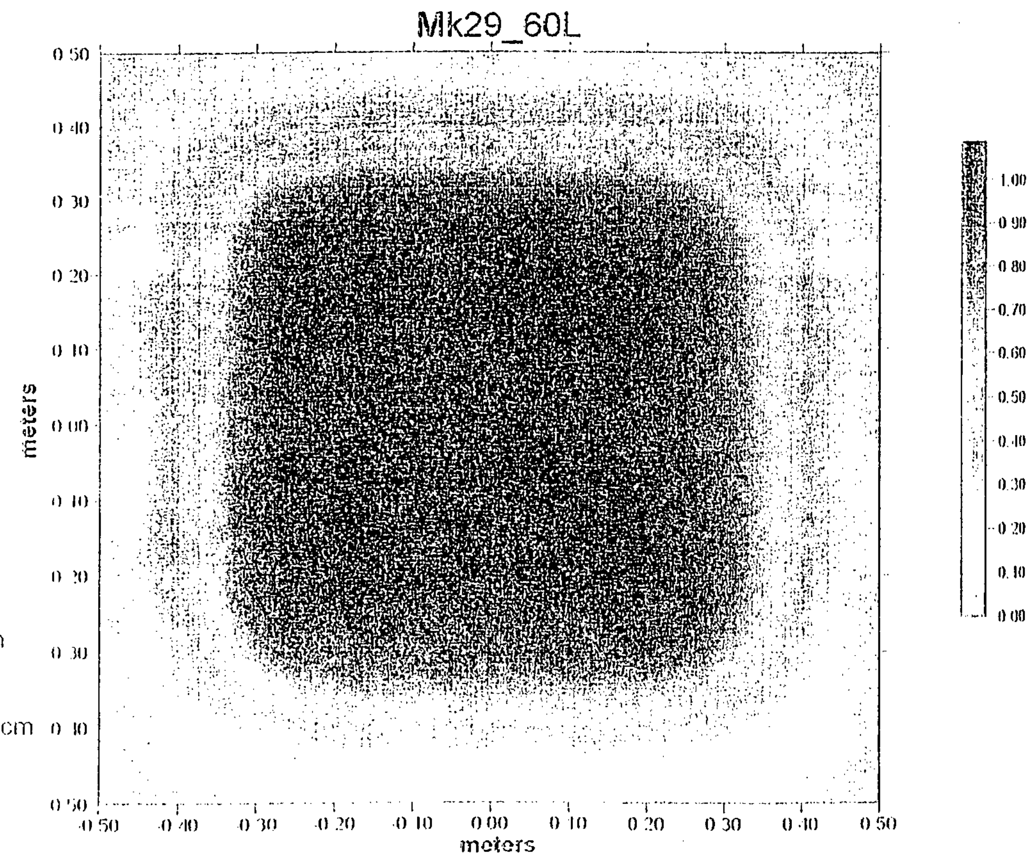
File Name: MK29_37.SR



Technology: ElectroMagnetic Induction
Locator: Mk 29
Location: Panama
Sensitivity: 7
Sensor Height (above center of target): 25 cm
Target: 37mm projectile
Target Orientation: (nose) N-S, not inclined
Maximum Detectable Height Over Target: 45 cm
Data Format: x,y,(0 or 1)



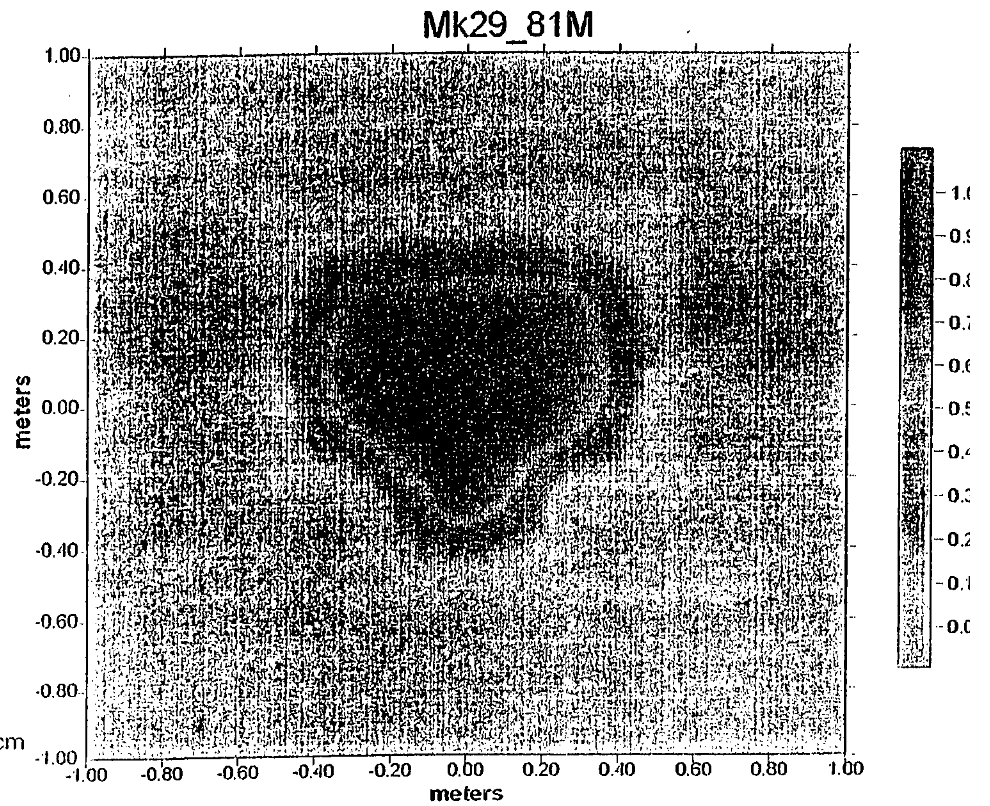
'echnology: ElectroMagnetic Induction
.ocator: Mk 29
.ocation: Panama
;ensitivity: 7
;ensor Height (above center of target): 50 cm
'arget: 60mm mortar
'arget Orientation: (nose) N-S, not inclined
/laximum Detectable Height Over Target: 50 cm
)ata Format: x,y,(0 or 1)



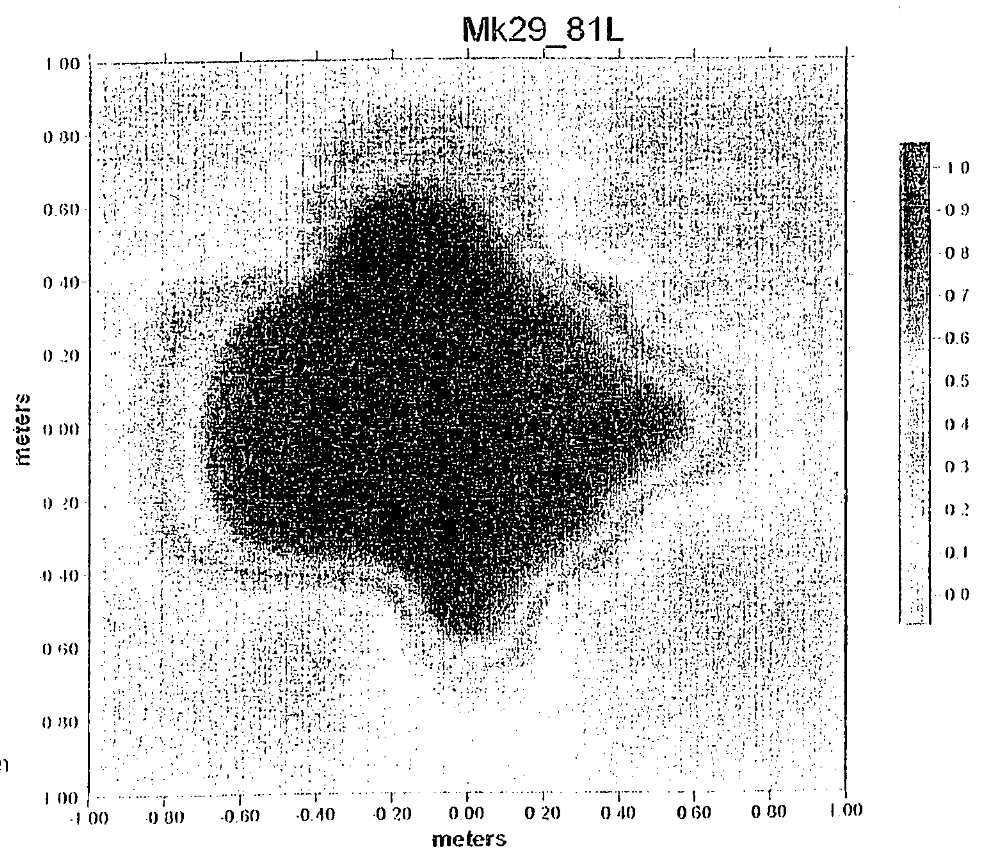
'echnology: ElectroMagnetic Induction
.ocator: Mk 29
.ocation: Panama
;ensitivity: 7
;ensor Height (above center of target): 25 cm
'arget: 60mm mortar
'arget Orientation: (nose) N-S, not inclined
/laximum Detectable Height Over Target: 50 cm
)ata Format: x,y,(0 or 1)

MAGNITUDE MAPS OF 81mm MORTAR

File Name: MK29_81.SF



Technology: ElectroMagnetic Induction
Locator: Mk 29
Location: Panama
Sensitivity: 7
Sensor Height (above center of target): 50 cm
Target: 81mm mortar
Target Orientation: (nose) N-S, not inclined
Maximum Detectable Height Over Target: 56 cm
Data Format: x,y,(0 or 1)

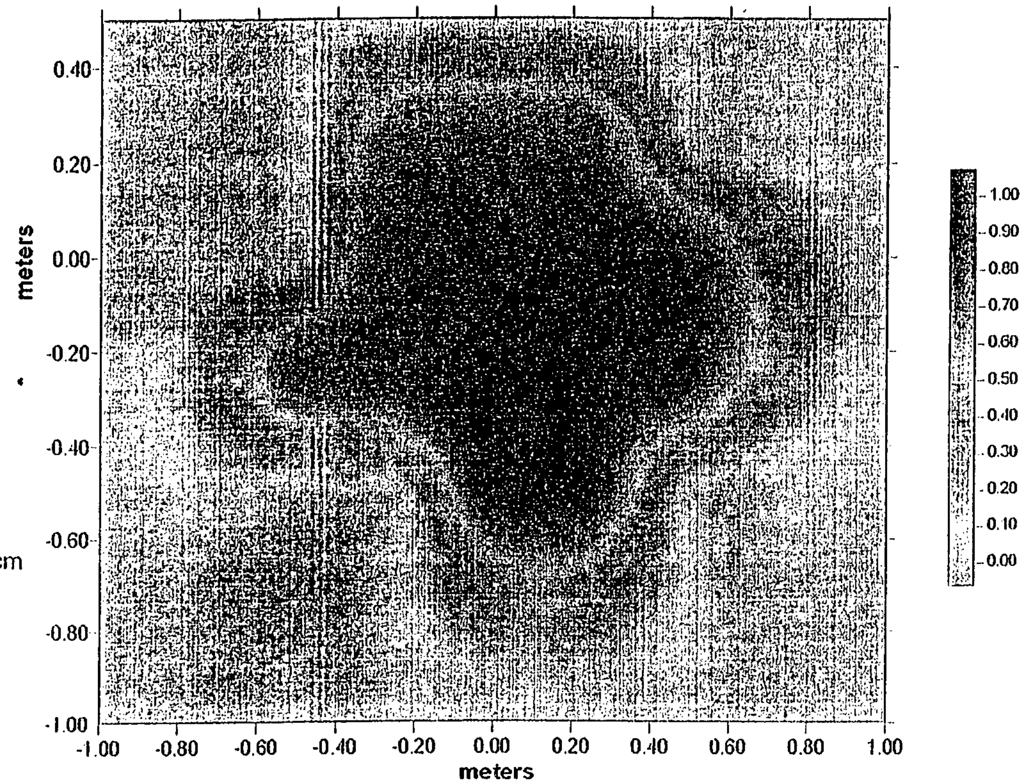


Technology: ElectroMagnetic Induction
Locator: Mk 29
Location: Panama
Sensitivity: 7
Sensor Height (above center of target): 25 cm
Target: 81mm mortar
Target Orientation: (nose) N-S, not inclined
Maximum Detectable Height Over Target: 56 cm
Data Format: x,y,(0 or 1)

MAGNITUDE MAPS OF 105mm PROJECTILE

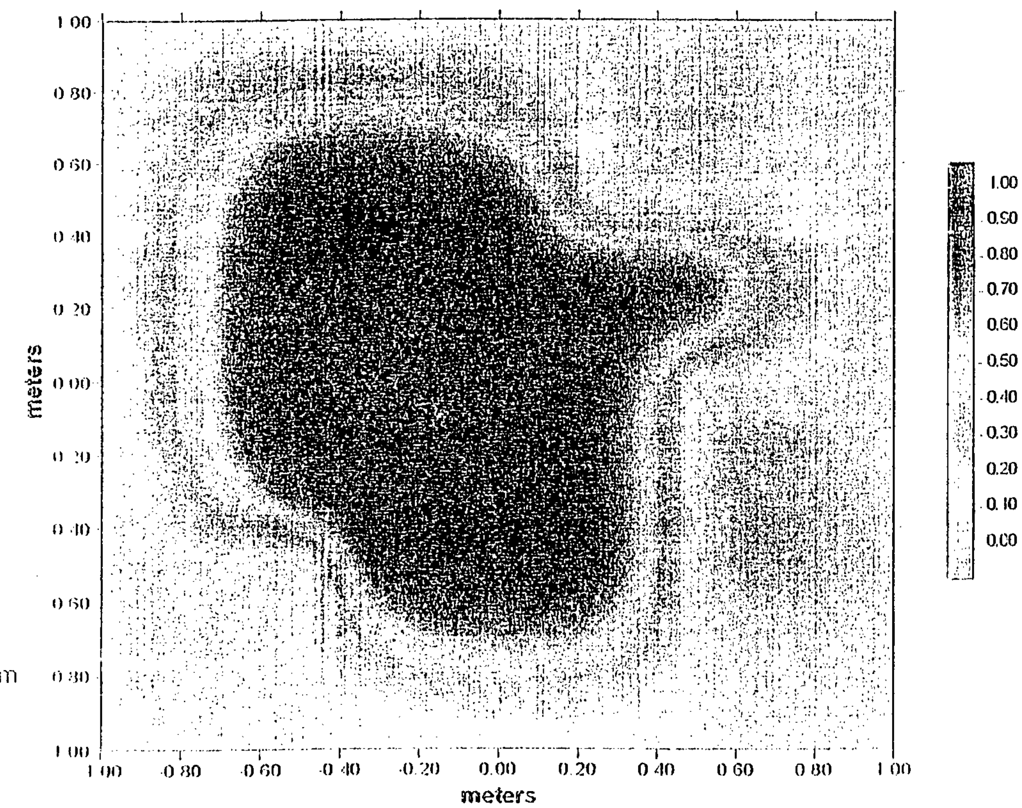
File Name: MK29_105.SRF

Mk29_105M



echnology: ElectroMagnetic Induction
ocator: Mk 29
ocation: Panama
ensitivity: 7
ensor Height (above center of target): 50 cm
arget: 105mm projectile
arget Orientation: (nose) N-S, not inclined
laximum Detectable Height Over Target: 64 cm
ata Format: x,y,(0 or 1)

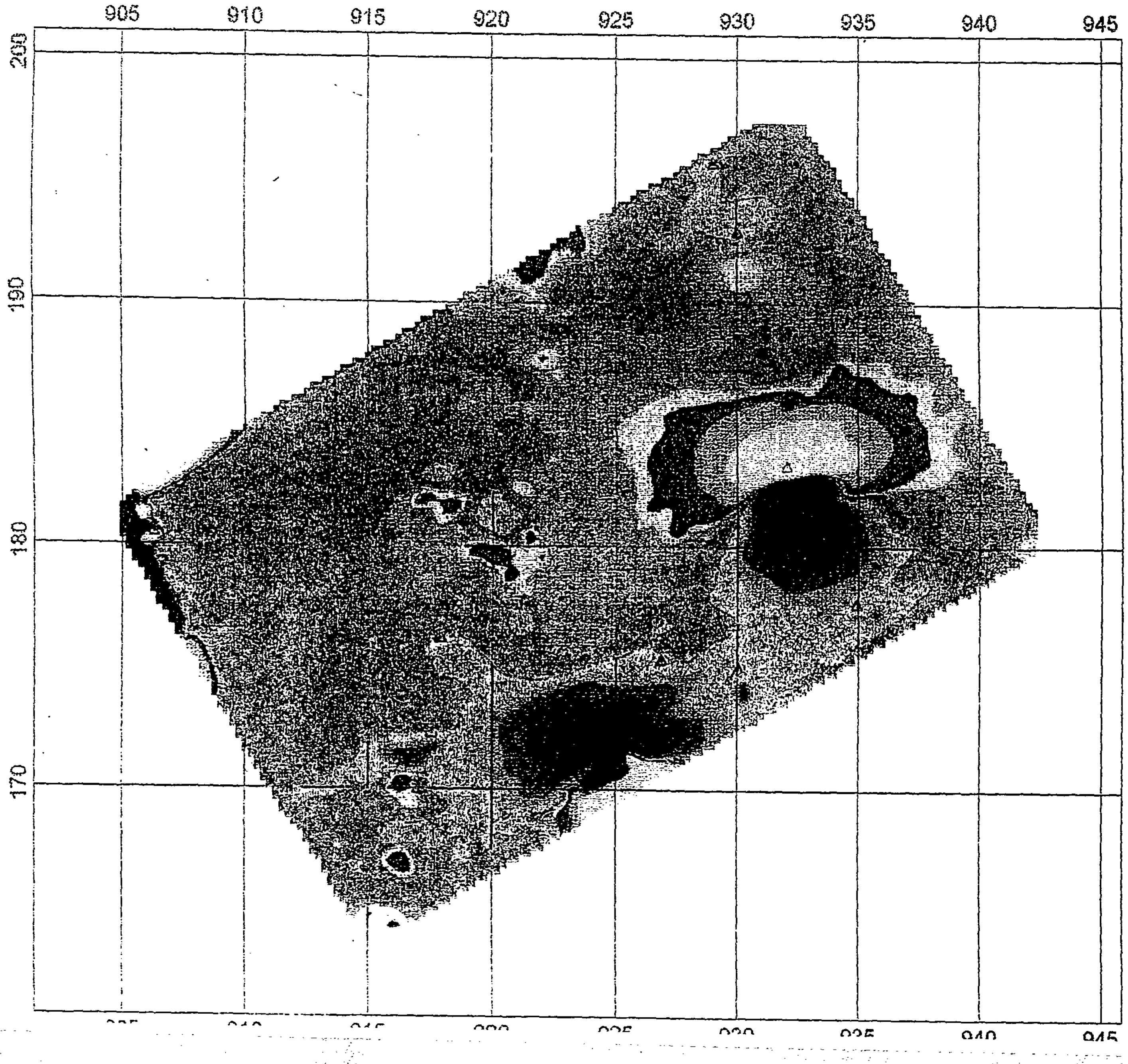
Mk29_105L

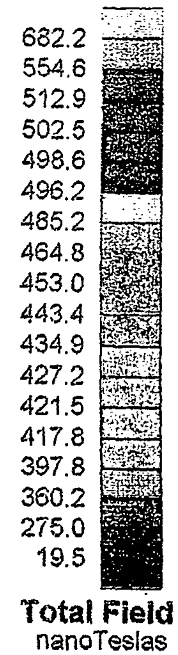


echnology: ElectroMagnetic Induction
ocator: Mk 29
ocation: Panama
ensitivity: 7
ensor Height (above center of target): 25 cm
arget: 105mm projectile
arget Orientation: (nose) N-S, not inclined
laximum Detectable Height Over Target: 64 cm
ata Format: x,y,(0 or 1)

Appendix C – Target Maps For The G858, EM61 Cart And EM61 HH On The Calibration Reference Area

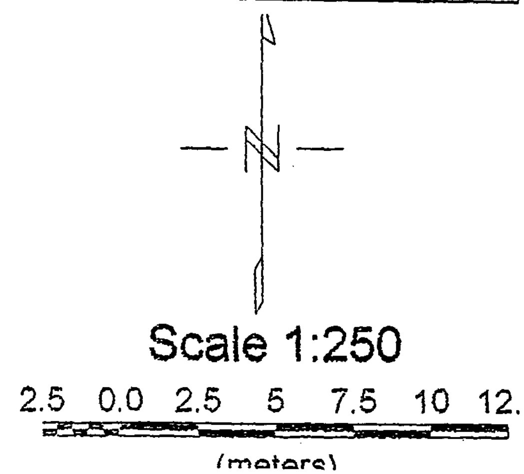
G868 Magnetic Target Declarations For The Calibration Reference Area



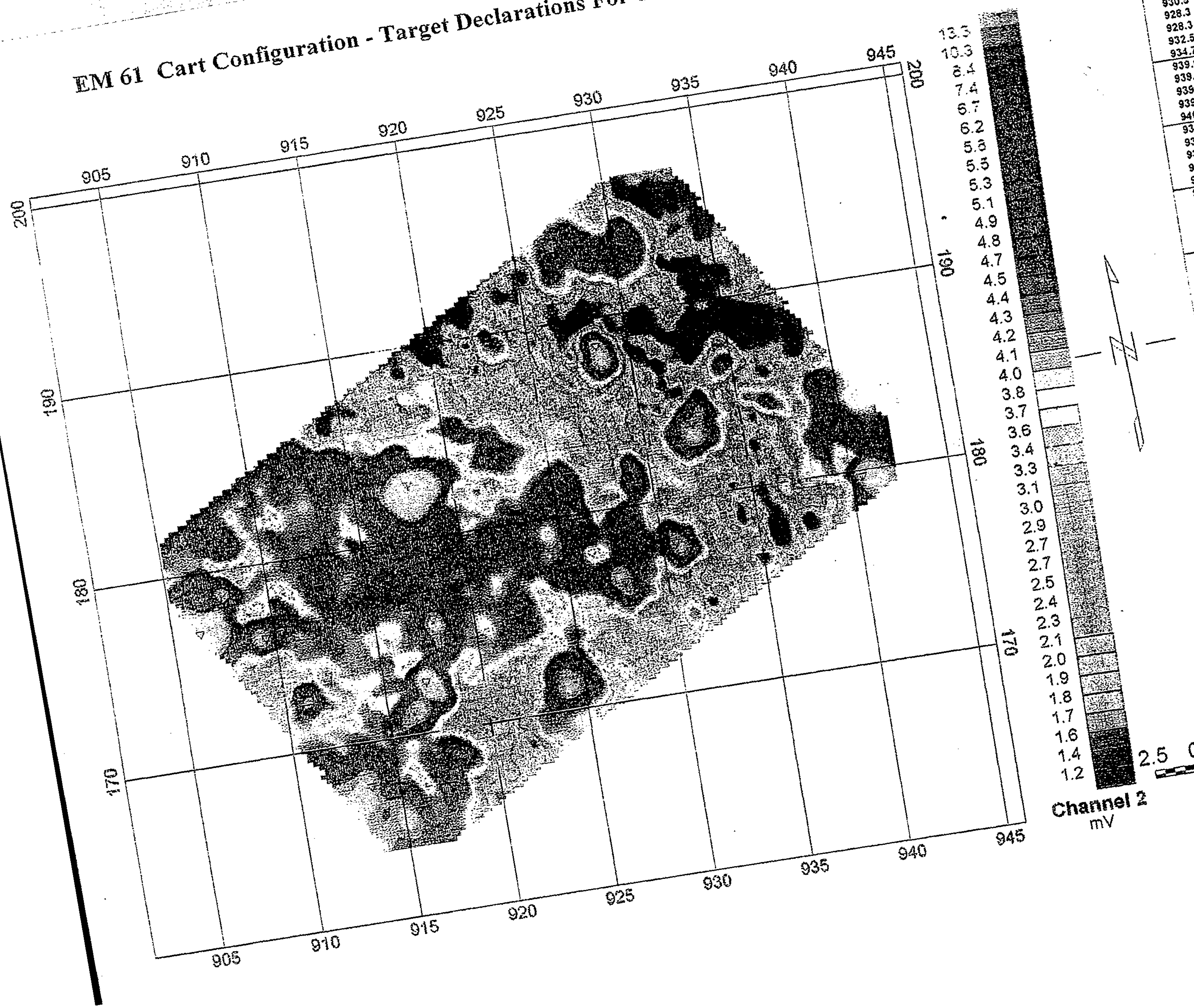


ANOMALY PICKS

East	North	nT
930.0	192.9	423.1
930.2	195.4	454.5
934.6	190.4	459.5
933.9	187.7	463.3
938.3	186.5	484.8
940.0	182.4	455.0
940.0	180.5	469.7
941.5	180.5	446.9
932.1	183.3	1992.2
934.9	177.6	407.0
930.0	175.0	432.6
926.8	175.3	428.0
923.6	170.5	369.6
923.5	191.8	486.4
921.4	190.9	499.9
921.8	189.5	485.0
921.1	187.6	471.9
921.1	185.3	471.3
919.4	178.9	456.6
920.6	182.1	453.3
921.3	177.8	481.1
917.9	176.2	438.8
917.7	174.4	447.9
917.6	172.3	448.9
915.5	172.3	450.0
916.7	168.7	456.9
915.9	166.3	470.0
913.0	168.7	462.7
911.7	170.5	466.1
911.2	172.1	452.6
911.0	172.1	450.8
910.2	173.9	456.7
912.2	174.1	452.7
909.5	175.7	461.4
907.5	177.8	458.7
906.8	179.0	444.9
906.3	180.5	403.4
909.8	181.9	463.1
909.7	178.7	461.4
910.3	180.8	462.5
915.9	179.0	462.2
917.1	181.9	494.7
918.1	187.0	466.2
911.0	182.1	455.3
927.0	193.4	451.0
930.5	196.1	463.1
929.0	195.7	434.9

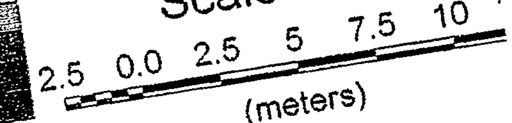


EM 61 Cart Configuration - Target Declarations For The Calibration Reference Area

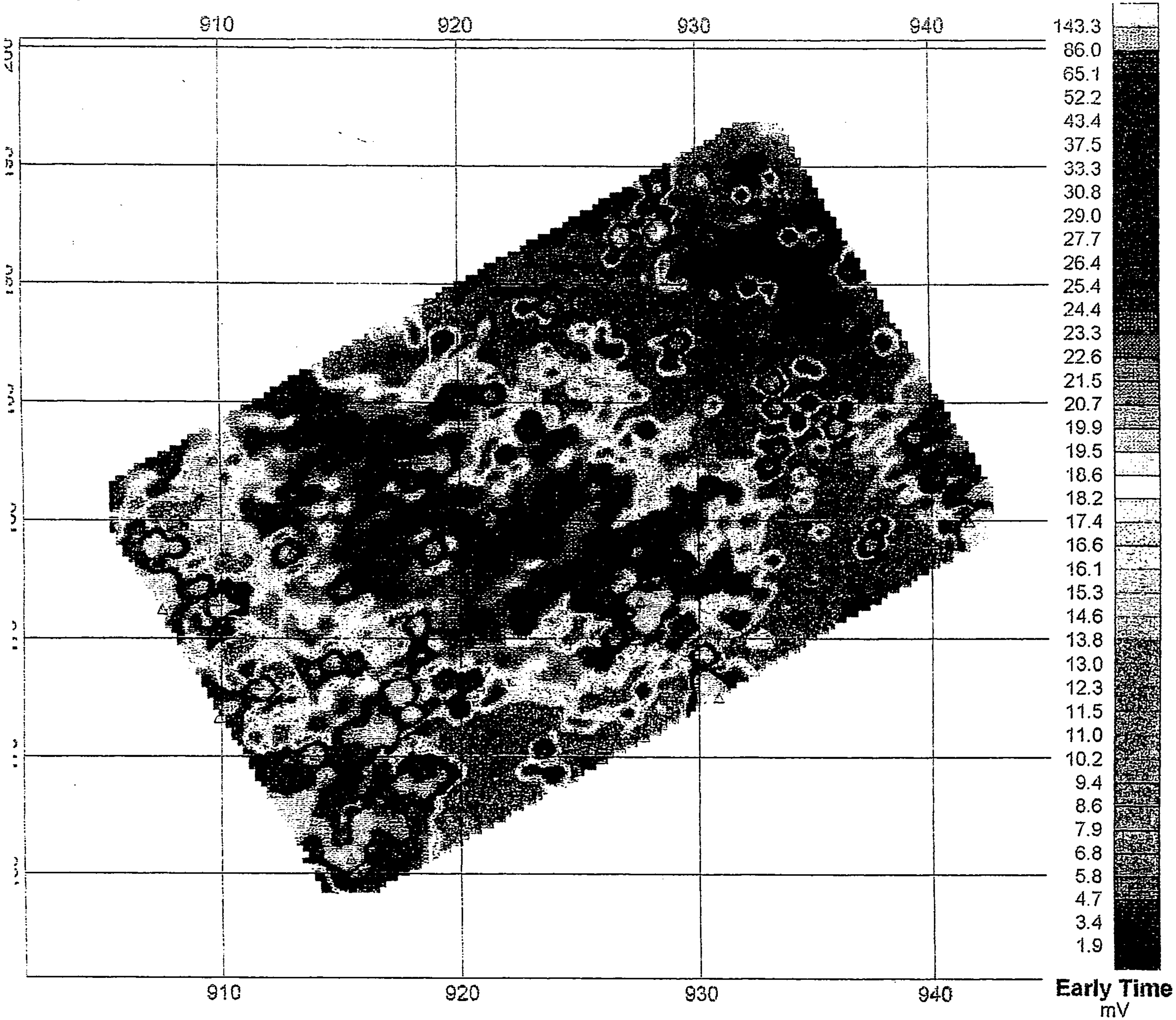


STANDARD EM-61 ANOMALY PICKS		
East	North	mV
930.5	193.3	7.5
928.3	193.7	1.5
928.3	188.5	8.4
932.5	183.8	10.1
934.7	186.8	-1.2
939.6	182.7	1.2
939.6	182.9	0.7
939.6	183.1	0.1
939.1	181.3	-1.5
940.6	179.7	13.9
934.9	176.3	-0.3
935.0	176.3	-0.4
930.7	177.8	7.4
928.8	181.6	0.2
928.3	178.6	1.2
927.8	176.2	6.0
924.5	171.6	11.4
925.3	177.2	-0.2
925.8	179.0	2.5
925.8	180.6	1.9
925.8	182.0	-1.0
923.3	189.6	-1.6
926.7	192.6	-1.7
922.3	183.9	0.8
920.6	185.5	-0.7
922.3	179.4	2.8
922.3	175.1	0.7
917.6	168.8	0.2
917.6	167.2	1.3
915.8	166.1	2.0
915.8	166.1	2.0
913.6	167.7	8.4
916.3	171.2	7.8
917.1	172.6	17.7
917.9	175.8	8.9
915.9	178.6	-0.8
914.8	177.1	0.8
917.8	182.9	57.5
914.1	183.9	1.8
912.6	185.0	-0.4
911.5	184.3	-0.2
910.6	181.5	-0.5
913.1	179.5	1.6
912.6	178.3	-0.1
907.4	182.2	0.2
907.5	179.4	1.7
910.2	177.9	-1.4
909.6	176.2	6.4
913.1	174.9	-1.6
911.1	172.3	4.4

Scale 1:250



EM61 HH Hand Held Configuration (With Optional Wheels) – Target Declarations For the Calibration Reference Area



HAND HELD EM-61 ANOMALY PICKS					
East	North	mV	East	North	mV
941.5	179.8	257.7	920.2	173.3	33.1
940.5	182.6	74.7	919.6	173.3	43.4
939.9	181.8	45.7	918.4	174.6	56.2
939.4	183.8	68.4	917.9	175.6	130.6
937.5	179.2	90.0	915.1	177.2	70.2
935.7	183.9	87.0	912.9	178.5	115.0
933.2	185.9	68.2	912.1	179.9	49.1
933.2	184.8	50.8	913.2	181.5	29.7
933.3	183.2	52.7	907.7	182.7	25.5
932.6	182.5	31.1	907.5	178.6	97.0
930.8	178.1	52.8	907.5	176.2	112.3
930.8	172.5	212.9	909.7	176.5	214.3
930.1	173.9	147.9	914.5	173.7	62.6
926.4	175.3	72.6	911.5	173.0	149.8
927.5	176.5	367.7	909.8	171.6	84.7
928.3	177.2	70.8	916.5	171.6	137.4
929.0	178.3	66.5	913.9	170.0	179.7
928.0	177.9	70.7	914.4	168.9	149.2
928.5	179.5	33.9	912.7	168.4	134.7
928.8	175.6	51.9	914.1	166.1	141.2
926.6	179.0	56.4	914.1	166.3	126.9
930.5	181.8	28.5	915.4	165.6	390.0
925.8	181.6	57.9	917.2	167.3	99.0
923.8	180.9	43.2	918.2	169.1	74.2
922.9	184.1	54.5	937.8	187.7	23.9
921.4	185.4	68.1	936.7	190.5	41.5
929.2	187.7	66.6	934.2	192.1	27.6
928.2	194.5	63.5	932.3	189.8	25.8
928.2	192.4	75.2	935.0	191.9	28.1
926.8	191.9	138.7	935.0	191.9	28.1
923.9	189.1	97.6	934.8	191.9	25.8
919.6	187.7	39.3	932.0	193.8	24.3
912.5	185.5	64.6	934.7	185.2	25.5
918.2	182.5	112.5	934.2	184.1	26.5
916.5	182.4	43.9	927.6	183.8	26.8
921.1	180.1	88.2	926.3	187.1	28.1
918.9	178.6	128.2	914.1	183.6	35.1
922.4	175.5	58.9	914.5	182.5	45.0
923.4	170.9	24.3			

Appendix D – SI Transect Data

Appendix D – Transect Data

EMPIRE RANGE

Transect	Distance	Compass Heading	GPS Coordinates (WGS 84, UTM, Zone 17)		Anomaly Number	Distance from transect origin	Anomaly Magnitude (EM61HH)	Estimated Depth	Actual Depth	Actual Anomaly	Picture ID	Dimensions	Weight
	(meters)	(deg.)	Easting	Northing		(meters)	(mV)	(meters)				(HxWxD cm)	(grams)
A1	30.00	252	649634	994520	1	6.8	20	<1	<25cm	mag. rock	NA		
					2	22.5	10	<1	<25cm	**frag**	**P000833**	**10.16x5.08x1.27**	**350**
A2	40.00	252			none	-	-	-	-	-	-	-	-
A3	44.80	252			none	-	-	-	-	-	-	-	-
A4	44.97	256			none	-	-	-	-	-	-	-	-
A5	94.00	256			none	-	-	-	-	-	-	-	-
A6	64.49	254			none	-	-	-	-	-	-	-	-
A7	33.00	252			none	-	-	-	-	-	-	-	-
B1	70.00	362	653315	994179	none	-	-	-	-	-	-	-	-
B2	100.00	362	-	-	1	68	70	<1	<25cm	mag. rock	NA		
B3	100.00	362	-	-	none	-	-	-	-	-	-	-	-
B4	70.00	362	-	-	1	37	150	<1	<25cm	mag. rock	NA		
B5	45.17	360	-	-	none	-	-	-	-	-	-	-	-
B6	35.08	312	-	-	none	-	-	-	-	-	-	-	-
B7	60.45	334	-	-	none	-	-	-	-	-	-	-	-
B8	22.07	334	-	-	none	-	-	-	-	-	-	-	-
B9	21.42	334	-	-	none	-	-	-	-	-	-	-	-
B10	138.56	NA	-	-	none	-	-	-	-	-	-	-	-
B11	80.00	NA	-	-	none	-	-	-	-	-	-	-	-
C1	100.00	15	645582	997482	1	2	15	<1	<25cm	mag. rock	NA		
			-	-	2	6.4	30	<1	<25cm	mag. rock	NA		
			-	-	3	27.5	25	<1	<25cm	mag. rock	NA		
			-	-	4	56.5	30	<1	<25cm	mag. rock	NA		

Transect	Distance	Compass Heading	GPS Coordinates (WGS 84, UTM, Zone 17)		Anomaly Number	Distance from transect origin	Anomaly Magnitude (EM61HH)	Estimated Depth	Actual Depth	Actual Anomaly	Picture ID	Dimensions	Weight
	(meters)	(deg.)	Easting	Northing		(meters)	(mV)	(meters)				(HxWxD cm)	(grams)
			-	-	5	71	150	<.5	<25cm	**BDU33**	**P000817**	**NA**	**NA**
			-	-	6	74.5	70	<1	<25cm	**frag**	**P000818**	**NA**	**NA**
			-	-	7	76.5	170	<.5	<25cm	mag. rock	NA		
			-	-	8	81.8	240	<.5	<25cm	mag. rock	NA		
			-	-	9	87.5	70	<1	<25cm	**frag,pipe,.223 ammo**	**P000819**	**20.32x12.7x1.27**	**1247.36**
			-	-						**frag,pipe,.223 ammo**	**P000819**	**21.59x2.54x2.54**	**354.36**
			-	-	10	95.5	130	<1	<25cm	**frag**	**P000831**	**NA**	**NA**
C2	100.00	15	-	-	1	17	60	<1	<25cm	nails,cart. links	P000815	8.26x.95x.95	14.18
			-	-	2	23	135	<.5	<25cm	**frag**	**P000835**	**12.07x13.34x.64**	**283.49**
			-	-	3	29	30	<1	<25cm	**fuze component**	**P000814**	**10.16x5.08x5.08**	**184.27**
			-	-	4	30.8	30	<1	<25cm	**grenade spoon**	**P000813**	**12.7x1.27x.16**	**14.18**
			-	-	5	37	70	<1	<25cm	mag. rock	NA		
			-	-	6	56.5	25	<1	<25cm	**frag,belt clip**	**P000812**	**NA**	**NA**
			-	-	7	89	155	<.5	<25cm	**frag**	**P000820**	**12.7x6.35x2.22**	**498.94**
			-	-	8	95	30	<1	<25cm	rock,pipe	P000821	35.56x2.54x2.54	544.3
			-	-	9	20	Mk 29	?	<25cm	**frag**	**P000834**	**5.08x13.97x.953**	**240.97**
C3	27.37	52	-	-	1	3.7	25	<1	<25cm	**frag**	**P000807**	**12.7x5.08x.64**	**212.62**
			-	-	2	18	50	<1	<25cm	mag. rock	NA		
C4	40.47	53.53	-	-	1	1.5	130	<.5	<25cm	**3.5" motor**	**P000797**	**26.67x8.89x8.89**	**1700.94**
			-	-	2	16	50	<1	<25cm	mag. rock	NA		
			-	-	3	22.5	70	<1	<25cm	**81mm fuze comp.**	**P000808**	**NA**	**680.38**
			-	-	4	26.7	180	<.5	<25cm	mag. rock	P000796	NA	NA
			-	-	5	31	20	<1	<25cm	mag. rock	NA		
			-	-	6	34.3	100	surface	<25cm	**frag (3 pieces)**	**P000797**	**17.78x5.4x.95**	**425.24**
											P000797	**7.62x5.08x1.27**	**240.97**
											P000797	**10.16x3.81x.95**	**170.09**
C5	47.69	49.23	-	-	1	4.3	100	surface	<25cm	mag. rock	P000798	NA	NA

Transect	Distance	Compass Heading	GPS Coordinates (WGS 84, UTM, Zone 17)		Anomaly Number	Distance from transect origin	Anomaly Magnitude (EM61HH)	Estimated Depth	Actual Depth	Actual Anomaly	Picture ID	Dimensions	Weight
	(meters)	(deg.)	Easting	Northing		(meters)	(mV)	(meters)				(HxWxD cm)	(grams)
			-	-	2	22.5	20	<1	<25cm	electric terminals	P000799	NA	NA
			-	-	3	27	80	surface	<25cm	reinforc. concrete	P000800	NA	NA
			-	-	4	38	190	<.5	<25cm	**flare holder,rocks**	**P000801**	**8.89x6.35x5.72**	**141.75**
			-	-	5	40.8	100	<.5	<25cm	wire	P000802	60.96x.48x.48	113.4
			-	-	6	44	25	<1	<25cm	wire*	NA	NA	63.79
			-	-	7	46	>200		<25cm	bunker	NA		
C6	41.13	52.22	-	-	1	9.3	60	<1	<25cm	**frag**	**NA**	**NA**	**NA**
			-	-	2	13.8	NA	NA	<25cm	**frag**	**P000803**	**NA**	**NA**
			-	-	3	18.3	50	<1	<25cm	**2 wires,fuze**	**P000804**	**6.03x4.45x1.27**	**56.7**
			-	-	4	33.7	40	<1	<25cm	**frag**	**P000805**	**15.24x16.51x.64**	**765.42**
C7	67.45	46	-	-	none	-	-	-	-	-	-	-	-
C8	32.53	46	-	-	1	15.5	110	<.5	<25cm	**105mm baseplate**	**P000806**	**NA**	**NA**
C9	37.82	47	-	-	none	-	-	-	-	-	-	-	-
C10	24.79	55	-	-	none	-	-	-	-	-	-	-	-
C11	47.17	50	-	-	none	-	-	-	-	-	-	-	-
C12	46.02	66.12	-	-	none	-	-	-	-	-	-	-	-
C13	43.49	66	-	-	none	-	-	-	-	-	-	-	-
C14	61.39	31.48	-	-	1	41.2	20	<1	<25cm	mag. rock			
			-	-	2	48.3	50	<1	<25cm	mag. rock			
C15	52.69	31.55	-	-	none	-	-	-	-	-	-	-	-
C16	35.50	72.03	-	-	1	21	30	<.5	<25cm	mag. rock			
C17	116.67	72.03	-	-	1	73.7	20	<.5	<25cm	mag. rock			
C18	12.90	101	-	-	1	7	70	<1	<25cm	**frag**	**NA**		
C19	22.61	71.24	-	-	none	-	-	-	-	-	-	-	-
C20	108.43	50.42	-	-	1	93.1	100	<.5	<25cm	mag. rock			
C21	63.78	64.26	-	-	1	35.5	200	surface	<25cm	**flare**	**NA**		
D1	64.47	78	-	-	1	22	25	<1	<25cm	geologic			
			-	-	2	26.6	20	<1	<25cm	geologic			

Transect	Distance	Compass Heading	GPS Coordinates (WGS 84, UTM, Zone 17)		Anomaly Number	Distance from transect origin	Anomaly Magnitude (EM61HH)	Estimated Depth	Actual Depth	Actual Anomaly	Picture ID	Dimensions	Weight
	(meters)	(deg.)	Easting	Northing		(meters)	(mV)	(meters)				(HxWxD cm)	(grams)
			-	-	3	38.8	20	<1	<25cm	geologic			
			-	-	4	41	40	<1	<25cm	no reading			
			-	-	5	46	40	<1	<25cm	mag. rock			
			-	-	6	56	>20	<1	<25cm	mag. rock			
D2	44.06	89.25	648673	995639	1	2	50	<1	<25cm	**frag**	**NA**		
D3	39.39	81.08	-	-	none	-	-	-	-	-	-	-	-
D4	73.44	52.47	-	-	1	47.4	100	<1	<25cm	**frag**	**NA**		
D5	35.15	64.13	-	-	none	-	-	-	-	-	-	-	-
D6	46.80	59.23	-	-	1	32.8	>1000	<.25	<25cm	mag. rock			
D7	50.57	184.11	-	-	1	50	100	<1	<25cm	mag. rock			
D8	15.09	184.11	-	-	none	-	-	-	-	-	-	-	-
E1	56.33	123.23	645735	997184	1	49.3	150	<1	<25cm	**frag**	**P000809**	**NA**	**NA**
E2	70.62	120.19	-	-	1	7.6	160	<1	<25cm	**frag**	**P000810**	**NA**	**NA**
			-	-	2	21.3	80	<1	<25cm	mag. rock			
			-	-	3	24	160	<1	<25cm	mag. rock			
			-	-	4	32	500	surface	<25cm	metal scrap			
E3	49.01	120.08	-	-	1	15.6	1000	<1	<25cm	**frag**	**P000811**	**NA**	**NA**
			-	-	2	33.8	50	<1	<25cm	mag. rock			
			-	-	3	34.6	50	<1		no reading			
			-	-	4	39.7	50	<1	<25cm	mag. rock			
			-	-	5	45.4	35	<1	<25cm	mag. rock			
E4	33.57	110.29	-	-	none	-	-	-	-	-	-	-	-
E5	48.25	112.13	-	-	1	6.8	50	<1		mag. rock			
E6	86.47	64.22	-	-	none	-	-	-	-	-	-	-	-
E7	46.47	75.16	-	-	1	1.5	40	<1	<25cm	mag. rock			
E8	110.73	91.26	-	-	1	78.7	80	<1	<25cm	mag. rock			
			-	-	2	83.4	25	<1	<25cm	mag. rock			
			-	-	3	85.7	25	<1	<25cm	mag. rock			
Bayonet										**2.75" rocket head**	**P000836**	**NA**	**NA**

BALBOA WEST RANGE

Transect	Distance	Compass Heading	GPS Coordinates (WGS 84, UTM, Zone 17)		Anomaly Number	Distance from transect origin	Anomaly Magnitude (EM61HH)	Estimated Depth	Actual Depth	Actual Anomaly	Picture ID	Dimensions	Weight
	(meters)	(deg.)	Easting	Northing		(meters)	(mV)	(meters)				(HxWxD cm)	(grams)
F1	74.26	87.53	640568	998528	1	12.2	130	<1	<25cm	**cart. links**	**P000783**	**NA**	**NA**
			-	-	2	14.9	100	<1	<25cm	**.223 cases**	**P000784**	**NA**	**NA**
			-	-	3	17.1	200	<1	<25cm	**.223 blanks**	**P000785**	**NA**	**NA**
F2	93.26	90.81	-	-	1	26.9	30	<1	<25cm	*no reading*	-	-	-
F3	93.47	93.1	-	-	none	-	-	-	-	-	-	-	-
F4	100.18	93	-	-	none	-	-	-	-	-	-	-	-
F5	20.3	131	-	-	none	-	-	-	-	-	-	-	-
F6	40.43	108.13	-	-	none	-	-	-	-	-	-	-	-
F7	59.55	74.41	-	-	none	-	-	-	-	-	-	-	-
F8	20.61	78.18	-	-	none	-	-	-	-	-	-	-	-
F9	64.86	77.48	-	-	none	-	-	-	-	-	-	-	-
F10	64.02	107.5	-	-	none	-	-	-	-	-	-	-	-
F11	45.67	41.22	-	-	none	-	-	-	-	-	-	-	-
F12	39.43	319	-	-	none	-	-	-	-	-	-	-	-
F13	42.63	294.15	-	-	none	-	-	-	-	-	-	-	-
F14	53.16	337.33	-	-	none	-	-	-	-	-	-	-	-
F15	46.78	1	-	-	none	-	-	-	-	-	-	-	-
F16	76.15	62.45	-	-	none	-	-	-	-	-	-	-	-
F17	70.12	121	-	-	none	-	-	-	-	-	-	-	-
G1	79.53	91	640560	999800	none	-	-	-	-	-	-	-	-
G2	14.38	91	-	-	none	-	-	-	-	-	-	-	-
G3	37.04	73.41	-	-	none	-	-	-	-	-	-	-	-
G4	29.09	166.53	-	-	none	-	-	-	-	-	-	-	-
G5	64.4	172.11	-	-	none	-	-	-	-	-	-	-	-
G6	97.59	161.06	-	-	none	-	-	-	-	-	-	-	-
G7	44.39	67.47	-	-	none	-	-	-	-	-	-	-	-
G8	27.85	24.11	-	-	1	1.2	250	<.5	<25cm	beer can	P000786	NA	NA
G9	30.25	24.11	-	-	none	-	-	-	-	-	-	-	-
G10	95.88	37.25	-	-	none	-	-	-	-	-	-	-	-

Transect	Distance	Compass Heading	GPS Coordinates (WGS 84, UTM, Zone 17)		Anomaly Number	Distance from transect origin	Anomaly Magnitude (EM61HH)	Estimated Depth	Actual Depth	Actual Anomaly	Picture ID	Dimensions	Weight
	(meters)	(deg.)	Easting	Northing		(meters)	(mV)	(meters)				(HxWxD cm)	(grams)
H1	63.09	30.3	640407	1000403	1	56.1	20	<.5	dug 1 ft.	no reading	-	-	-
H2	42.42	59.33	-	-	none	-	-	-	-	-	-	-	-
H3	94.31	42.13	-	-	none	-	-	-	-	-	-	-	-
H4	131.12	58.12	-	-	1	16.5	20	<1	dug 1 ft.	no reading	-	-	-
			-	-	2	50.5	500	surface	<25cm	**20mm link**	**P000788**	**8.26x7.62x3.18**	**42.52**
			-	-	3	74	100	<1	<25cm	**frag**	**P000789**	**10.16x3.18x.95**	**148.83**
			-	-	4	80	100	<1	<25cm	**frag**	**P000790**	**6.35x2.54x.95**	-
H5	92.8	61.15	-	-	1	65	30	<1	dug 1 ft.	no reading	-	-	-
H6	33.8	64.53	-	-	none	-	-	-	-	-	-	-	-
H7	58.16	67.07	-	-	1	32	30	<1	dug 1 ft.	no reading	-	-	-
J1	118.18	305	640371	1000326	none								
J2	26.34	270	-	-	1	17.3	40	<1		**20mm cart**	**P000791**	**10.16x3.18x3.18**	**113.4**
J3	79.25	247	-	-	1	8	12	<1		mag. rock	-	-	-
J4	27.79	262.31	-	-	none	-	-	-	-	-	-	-	-
J5	109.04	271	-	-	none	-	-	-	-	-	-	-	-
J6	56.87	271	-	-	none	-	-	-	-	-	-	-	-
J7	56.06	278	-	-	none	-	-	-	-	-	-	-	-
J8	31.73	278	-	-	1	29.2	30	<1		**20mm,clip**	**P000792**	**NA**	**85.05**
J9	54.86	276	-	-	1	23	125	<1		**2.75" rocket fin**	**P000795**	**15.24x3.18x.32**	**42.52**
K1													
K2													
K3													
K4													
K5													
K6													
K7													

PINA RANGE

Transect	Distance	Compass Heading	GPS Coordinates (WGS 84, UTM, Zone 17)		Anomaly Number	Distance from transect origin	Anomaly Magnitude (EM61HH)	Estimated Depth	Actual Depth	Actual Anomaly	Picture ID	Dimensions	Weight
	(meters)	(deg.)	Easting	Northing		(meters)	(mV)	(meters)				(HxWxD cm)	(grams)
L1	117.25	256.28	615033	1021490	1	33.2	620	<.25	<25cm	milk crate	P000745	39.37x33.02x29.85	>2.2 kg
L2	80.47	272.74	-	-	none	-	-	-	-	-	-	-	-
L3	62.42	294.21	-	-	none	-	-	-	-	-	-	-	-
L4	56.15	210.36	-	-	none	-	-	-	-	-	-	-	-
L5	112.18	188.44	-	-	none	-	-	-	-	-	-	-	-
L6	61.37	200.41	-	-	none	-	-	-	-	-	-	-	-
L7	88.56	224.35	-	-	none	-	-	-	-	-	-	-	-
M1 (@L5)	66.21	243.19	-	-	none	-	-	-	-	-	-	-	-
M2	64.64	259.5	-	-	1	49	350	<.25	<25cm	**M16 mag.**	**P000746**	**NA**	**NA**
M3	144.63	288.17	-	-	none	-	-	-	-	-	-	-	-
N1	75.76	302.5	614687	1018735	1	5.5	70	<1	<25cm	beer can			
			-	-	2	13.2	500	<1	<25cm	barbed wire			
N2	77.55	311.23	-	-	1	67.2	300	surface	<25cm	**40mm Prac.**	**NA**		
N3	56.56	310.25	-	-	none	-	-	-	-	-	-	-	-
N4	134.76	298.29	-	-	none	-	-	-	-	-	-	-	-
N5	36.45	320.13	-	-	none	-	-	-	-	-	-	-	-
N6	68.1	347.11	-	-	1	60.6	20	<.5		no reading			
N7	44.58	339.42	-	-	none	-	-	-	-	-	-	-	-
N8	60.36	306.07	-	-	none	-	-	-	-	-	-	-	-
N9	28.74	255.25	-	-	none	-	-	-	-	-	-	-	-
N10	31.08	270.06	-	-	none	-	-	-	-	-	-	-	-
N11	31.05	320.24	-	-	none	-	-	-	-	-	-	-	-
N12	41.9	285	-	-	none	-	-	-	-	-	-	-	-
N13	103.23	304	-	-	none	-	-	-	-	-	-	-	-

P1	102.24	89.37	610310	1018305	none								
P2	167.61	91	-	-	1	32	40	<1		no reading	-	-	-
P3	64.04	83.37	-	-	none	-	-	-	-	-	-	-	-
P4	124.98	70.2	-	-	none	-	-	-	-	-	-	-	-
P5	60.55	68.45	-	-	none	-	-	-	-	-	-	-	-
P6	74.45	66.41	-	-	1	69.45	painted		<25cm	battery	P000764		
P7	74.5	75.45	-	-	1	59.5	45	<1	<25cm	**frag**	**P000755**	**10.16x5.72x1.27**	**269.32**
			-	-	2	62.2	25	<1	<25cm	**frag**	**P000756**	**7.62x3.18x1.27**	**92.13**
			-	-	3	64.3	50	<1	<25cm	**frag**	**P000754**	**15.24x6.99x1.91**	**680.38**
P8	92.07	88.42	-	-	1	18.8	35	<1	<25cm	**base plate**	**P000757**	**10.5x10.5x3.0**	**1332.4**
			-	-	2	33.4	50	<1	<25cm	**frag**	**P000758**	**10.48x6.35x1.27**	**269.32**
			-	-	3	51.6	55	<1	<25cm	**frag**	**P000759**	**10.8x3.18x1.91**	**155.92**
			-	-	4	58	80	<1	<25cm	**frag**	**P000760**	**NA**	**NA**
P9	80.71	68.01	-	-	1	61.6	25	<1	<25cm	**frag**	**P000761**	-	-
P10	10.74	159.03	-	-	none	-	-	-	-	-	-	-	-
P11	37.52	74.04	-	-	none	-	-	-	-	-	-	-	-
P12	44.74	106.32	-	-	none	-	-	-	-	-	-	-	-
P13	82.73	106.32	-	-	1	51	25	<1		**frag**	**P000762**	**NA**	**NA**
					2	66.7	40	<1		**frag**	**P000763**	**NA**	**NA**
		hand compass only											
Q1	150	35	611978	1017276	1	50.7	10	<.5	<25cm	nails	P000746		
			-	-	2	52.8	55	<1	<25cm	nails	P000747		
			-	-	3	54	80	<1	<25cm	nails	P000748		
			-	-	4	55	150	<1	<25cm	nails	P000749		
Q2	79	42	-	-									
Q3	25	17	-	-									
Q4	54	335	-	-									

Appendix E – Acronym List

ARTS	All Purpose Remote Transport System
ATD	Advanced Technology Demonstration
bgs	Below Ground Surface
cm	Centimeters
DGPS	Differential Global Positioning System
DoD	Department of Defense
EE	Engineering Evaluation
EM	Electromagnetic
EOD	Explosive Ordnance Disposal
FAR	False Alarm Ratio
GOP	Government of Panama
GPR	Ground-Penetrating Radar
GPS	Global Positioning System
HH	Hand Held
ILEVR	Installation Logistics Environmental Restoration
IR	Infrared
JPG	Jefferson Proving Grounds
NAVEODTECHDIV	Naval Explosive Ordnance Disposal Technology Division
P_D	Probability of Detection
QA	Quality Assurance
RF	Radio Frequency
SI	Site Investigation
TIPA	Treaty Implementation Plan Agency
TM	Technical Manual
USAEC	United States Army Environmental Center
USAF	United States Air Force
USARSO	United States Army South
UXO	Unexploded Ordnance
WES	Waterways Experiment Station